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LEACHATE COLLECTION AND GAS MIGRATION AND EMISSION PROBLEMS AT LANDFILLS AND SURFACE IMPOUNDMENTS

by

Masood Ghassemi, Kimm Crawford and Michael Haro
MEESA
San Pedro, California 90732

EPA Contract No. 68-03-1828

Project Officers:

Norma Lewis and Vincent Salotto
Land Pollution Control Division

HAZARDOUS WASTE ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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16. ABSTRACT

Clogging of leachate systems and gas migration and emission problems were evaluated at hazardous waste landfills and surface impoundments. Collective and preventive measures were identified along with research and development needs. The analysis used literature and information obtained by interviews with experts at 16 design firms, state regulatory agencies, and public organizations.

Problems related to leachate collection systems and gas emissions can best be addressed through preventive measures involving design, construction, and operation practices. These measures are aimed at reducing leachate and gas generation by improving leachate management, cell-by-cell design, waste segregation and disposal, design redundancies, and using flexible membrane liners.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Research Engineering Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This document presents an analysis of problems and applicable preventive and corrective measures for hazardous waste landfills and surface impoundments. The areas addressed include landfill leachate collection systems and atmospheric emissions and controls for landfills and surface impoundments. The analysis draws upon the published literature which was supplemented by data and information obtained through discussions with some sixteen design engineering firms, owners and operators of hazardous waste management facilities, and cognizant state regulatory agencies. The findings will be useful to operators and owners of hazardous waste sites as well as design engineers who need to initiate corrective measures. For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

David G. Stephan
Director
Hazardous Waste Engineering
Research Laboratory

ABSTRACT

Potential problems with leachate collection systems (LCS) in hazardous waste landfills (HWLF), gas migration and emissions problems at HWLF, and gas emission problems at surface impoundments (SI) were evaluated; applicable corrective and preventive measures together with research and development (R&D) needs were identified. Published literature and information obtained through discussions with experts at sixteen engineering firms, state regulatory agencies and public and commercial waste management companies or organizations were used in the analysis.

There has been limited operating experience with properly designed LCS and hence very little opportunity for corrective action at such sites. Most clogging problems are expected to be localized and of minimum consequence due to many excess design features which are incorporated. Gas generation and migration problems are largely associated with municipal and co-disposal landfills and are not generally applicable to HWLFs where there would be little biological activity. Very limited gas emission data have been developed for HWLFs; and ambient concentrations of most gaseous pollutants at SIs are near the detection limits of the sampling and analytical procedures used.

Leachate collection systems problems and gas-/emission-related problems at HWLFs and SIs can best be addressed through preventive measures such as incorporating design redundancies or waste pretreatment.

Areas for R&D include development of improved basis for LCS design, evaluation of innovative approaches to LCS design, evaluation of cost-effective methods for retrofitting older sites with LCS, parametric evaluation of various cover systems for landfills from the standpoint of emissions control, and evaluation and expansion of the current data base on emissions.

This report was submitted in fulfillment of Contract No. 68-03-1828 by MEESA under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period of September 1983 to February 1985 and work was completed as of February 1985.

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ABBREVIATIONS

AQMD	--	Air Quality Management District
ASTM	--	American Society of Testing and Materials
CARB	--	California Air Resources Board
cm	--	Centimeter, centimeters
C-P	--	Concentration profile
CPE	--	Chlorinated polyethylene
CSI	--	Confined space indicators
cu ft	--	Cubic foot, cubic feet
cu yd	--	Cubic yard, cubic yards
Eq.	--	Equation
FML	--	Flexible membrane liner
gal	--	Gallon, gallons
GC	--	Gas chromatography
GC-MS	--	Gas chromatography-mass spectrometry
Ha	--	Hectare, hectares
HW	--	Hazardous waste
HDPE	--	High density polyethylene
HWLF	--	Hazardous waste landfill
IERL-Ci	--	Industrial Environmental Research Laboratory in Cincinnati (EPA)
IFC	--	Isolation flux chamber
in.	--	inch, inches
kg	--	Kilogram, kilograms
LCS	--	Leachate collection system
LDS	--	Leak detection system
LF	--	Landfill
MERL	--	Municipal Environmental Research Laboratory (EPA)
MMCF	--	Million cubic feet
MWLF	--	Municipal waste landfill
OSHA	--	Occupational Safety and Health Administration
PE	--	Polyethylene
ppbv	--	Parts per billion concentration by volume
ppm	--	Parts per million
PVC	--	Polyvinyl chloride
QA/QC	--	Quality assurance/quality control
Ref.	--	Reference
RCRA	--	Resource Conservation and Recovery Act
R&D	--	Research and development

SCAQMD -- South Coast Air Quality Management District (Southern California)
sec -- Second, seconds
SHWRD -- Solid and Hazardous Waste Research Division (of EPA's MERL)
SI -- Surface impoundment
SLF -- Secure landfill
sq ft -- Square foot, square feet
T.D. No. -- Technical discussion summary reports presented in Section 7
TLV -- Threshold limit value
TSDF -- Treatment, storage and disposal facilities
uv -- Ultraviolet
VOC -- Volatile organic compounds
yr -- Year, years

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SECTION 1

INTRODUCTION

EPA's Hazardous Waste Engineering Research Laboratory (HWERL) is investigating the use of landfills (LFs) and surface impoundments (SIs) in hazardous waste management. The primary aims of this research are to develop criteria for improved disposal site design and operation and to identify potential problem areas and applicable corrective measures. The research results are made available to the user community (i.e., site designers and construction engineers, owners and operators of hazardous waste management facilities, regulatory/permitting agencies and researchers) through the publication of technology transfer type documents such as this report.

Potential problem areas identified as requiring studies to better define the nature and extent of each problem area and applicable corrective measures include (a) leachate collection systems in hazardous waste landfills (HWLF), (b) gas migration and emission problems at HWLF, and (c) gas emission problems at surface impoundments (SI).

A literature review indicated very little information available in the areas of interest. Accordingly, the data base development effort for this study has relied heavily on acquisition of information from design engineers, owners and operators of land disposal facilities and cognizant state regulatory agencies.

This document is organized into 5 sections and two appendices. This first section reviews the background and the intended uses of this document. Section 2 presents the conclusions of the study, including R & D recommendations. Section 3 describes the methodology for data acquisition and identifies individuals and organizations providing input to the study in connection with the technical discussions-with-experts element of the program. Sections 4 presents a review of the previous studies and the results of the present study regarding LCS problems and applicable corrective and preventive measures. Similar discussion for gas migration and emissions control is presented in Section 5. The discussions in Sections 4 and 5 draw heavily on the information collected in technical discussions with various individuals and organizations with expertise in the subject areas; summary reports on individual discussions are presented in Appendix A.

Tabular summaries of corrective and preventive measures for liner and cover systems are presented in Appendix B, based largely on the information in previous studies.

The individuals and organizations whose perspectives are included in Appendix A represent some of this country's leading design engineering firms, process developers (for landfill gas recovery) and regulatory agencies of states which have been in the forefront of regulatory development and enforcement activities. To this end, and insofar as that not all the materials contained in Appendix A have been covered or discussed in detail in the remaining sections of the report, Appendix A has been organized as an independent section and is recommended for review as an independent output of the present effort. Based on the feedback received on the reports for two predecessor studies (1,2), which included similar compendiums of professional perspectives, regulatory agencies, owners and operators of waste disposal sites, researchers and design engineers should find Appendix A very informative and of value to them in broadening their own perspectives. Some differences of opinions which are expressed are generally more reflective of the differences in the nature of problems encountered in different regions of the country than the differences in the approach to solving the same problem.

SECTION 2

CONCLUSIONS AND R&D RECOMMENDATIONS

2.1 LEACHATE COLLECTION SYSTEM (LCS)

- There is very limited experience with properly designed LCS at hazardous waste landfills (HWLFs). Much of the documented problems with the existing LCS relate to older municipal or co-disposal sites which lacked sophisticated designs, did not incorporate design redundancies and in many cases consisted merely of simple toe drains, interceptor pipes or gravel drains. These systems were also poorly constructed and received little or no QA/QC attention. Some designers believe that even if some clogging occurs, the problem should not be of any major consequence due to the extreme redundancies (excesses) which would be incorporated in the state-of-the-art designs.

- The actual or potential problems with LCS (and with gas generation, migration and emissions) at HWLFs can best be addressed through preventive measures incorporated in design and operating practices.

- Design efforts for improving site performance from the standpoint of leachate management and LCS functioning are aimed at minimizing potential for leachate generation, improving leachate control capability and reducing impact on LCS and the consequence of any localized malfunction. These preventive design-related measures include: (a) use of progressive designs which allow for some experimentation and incorporation of experience from previous cells and which limits the active life of a cell to only 2 to 3 years, (b) employing the state-of-the-art liner and cover designs including interception of subsurface water, (c) use of multiple cells for segregated waste disposal, (d) incorporation of much redundancies (excesses) in design, (e) traffic routing to avoid excessive stress on collection pipes, (f) automatic leachate pumping, (g) use of specially fabricated pipe connectors and sweep bends, (h) freeze protection of pipes, and (i) use of suitable slopes and protective cover for landfill side slopes and geotextile liners for LCS trenches.

- Operating controls for preventing LCS failure and for mitigating other leachate management problems include: source control (i.e., placing restrictions on type of wastes, such as liquids, which can be accepted in a landfill), waste neutralization/inactivation prior to disposal, surrounding specific waste loads with absorbents or neutralizers, placing the potentially troublesome wastes near top and definitely not in the first lift, use of permeable material as intermediate cover, use of temporary domes or roofs during operation, and rigorous implementation of inspection and maintenance programs, including demonstration of the functioning of the LCS after the first or second lift of waste is in place.

- Although there has been little opportunity for corrective actions at RCRA-designed hazardous waste sites and situations requiring drastic reparative measures are not anticipated at such sites, some such measures which have been used at older municipal and co-disposal sites may be applicable to and constitute contingency measures for RCRA sites. These reparative measures, some of which have proved too costly and expensive substitutes for preventive design and operating measures, include use of barriers such as slurry trench to contain leachate, use of gravel trenches and pipes to intercept seepage, installing caissons in landfills and pumping out the perched leachate, and replacing sections of the collection system.

2.2 GAS GENERATION, MIGRATION AND EMISSIONS AT HWLFs

- Gas generation and migration problems which are encountered at municipal and co-disposal landfills would not be a concern at strictly hazardous waste sites. Because of the extreme toxicity of waste and the operating practice of not accepting putrescible wastes, little, if any, biological activity resulting in production of decomposition gases is expected at these sites. Pressure monitoring inside the capped gas vents at some closed hazardous waste sites has not indicated a buildup of gas pressure.

- Much of the recent emissions monitoring and source testing efforts at hazardous waste landfills have been concerned with development and field evaluation of sampling and analysis protocols and with verification of predictive models.

- The current emissions data base indicates that even though closed hazardous landfills may emit some VOCs, the measured/calculated ambient concentration levels of specific compounds are very low (usually near or below the detection limits of the methods employed) and nearly always less than the permissible OSHA exposure levels. These results, however, may not be valid or representative because of (a) the limited number of sites tested, (b) the existence of multiple sources of emissions at or in the vicinity of facilities tested, and (c) the wide variations in the results obtained using different protocols.

- Preventive/corrective design-related measures for gas generation, migration and emissions control at hazardous waste landfills include use of multiple cells for segregated waste disposal, state-of-the-art liner and cover designs, and capping of vents, sumps and cleanouts. Operation-related measures for reducing landfill emissions include source control (i.e., not accepting, or restricting disposal of, solvents, putrescible wastes or liquids), use of permeable material as intermediate cover (to avoid barriers to gas flow) and control of runoff and infiltration thereby suppressing potential for leachate generation and biological activity. Fugitive emissions due to waste handling and placement activities can be reduced by limiting the exposed working face of landfill, operating under low temperature and low wind speed (when possible), covering waste with suitable material immediately after disposal, and processing waste in enclosed areas equipped with emissions control.

2.3 GAS MIGRATION AND EMISSIONS CONTROL AT MUNICIPAL AND CO-DISPOSAL SITES

- Gas generation and migration are problems primarily associated with co-disposal and municipal landfills where the waste undergoes decomposition. Landfill gas contains primarily methane (which presents explosion hazards) and carbon dioxide, but also traces of hydrogen sulfide, hydrogen, ammonia and aliphatic, aromatic and chlorinated organics (e.g., vinyl chloride). In general, the quantity and characteristics of landfill gas are highly variable and extremely site-specific and these variations are not necessarily related to any regulatory or conventional classification of sites as co-disposal, sanitary, etc.

- Unless it is recovered, in addition to safety hazards associated with its offsite migration, landfill gas can constitute a major source of air pollution, emitting large quantities of reactive organics and substantial amounts of potentially hazardous substances which are present in the gas as trace constituents. Landfill covers will not prevent, but merely postpone, gas emissions. Passive controls involving interception and direct atmospheric venting of gas can eliminate the gas migration problem but would not constitute an emissions control measure.

- Properly designed and operated active gas control systems can provide for both emissions and gas migration control. These systems use blowers to collect gas through a network of extraction wells and/or trenches. The collected gas is either disposed of by flaring or combusted for energy recovery. In either case, a high degree of destruction of toxic organics can be achieved when combustion temperatures are kept at about 800°C or greater.

2.4 EMISSIONS CONTROLS FOR HAZARDOUS WASTE SURFACE IMPOUNDMENTS

- As with HWLFS, much of the emissions monitoring and source testing efforts at hazardous waste surface impoundments have been concerned with methods development and verification of predictive models. Results also indicate ambient concentration levels close to detection limits of the analytical procedures used, large variations between results using different methods, and large discrepancies between measured values and estimated levels using models.

- Preventive and corrective measures for reducing VOC emissions from surface impoundments include source control, proper siting, site enclosure and use of floating cover, surface films, competitive solvent phase and wind fences. Source control (which may include waste pretreatment for VOC removal) is considered by many to be the most viable approach to emissions control.

2.5 R&D RECOMMENDATIONS

- Development of improved basis for LCS design through case studies of LCS performance in full-scale facilities and long-term parametric studies at full-scale sites reflecting actual field operating conditions and practices.

- Evaluation of cost-effective approaches to retrofitting older sites with LCS.

- Development of reliable systems for monitoring the functioning of LCS.

- Evaluation of innovative design concepts to leachate collection such as the draining of the entire LCS trench or blanket and not merely the embedded pipe or the possible use of a single system to simultaneously collect leachate and the gas.

- Parametric evaluation, in "real world" facilities, of various cover systems for landfills from the standpoint of emissions control.

SECTION 3

DATA BASE DEVELOPMENT METHODOLOGY

As noted in Section 1, only limited information could be found in the literature regarding the potential operating problems associated with leachate collection and gaseous emissions at hazardous waste disposal sites. To expand the data base for the study, results from recent and on-going EPA-sponsored studies were included. Also information was obtained from owners and operators of certain waste disposal sites, personnel of cognizant regulatory permitting agencies and several leading consulting engineering firms engaged in design and construction of LFs and SIs. Table 1 lists the 16 organizations that contributed to the study.

Information was obtained on the following topics:

- Leachate Collection System

  -Actual experience with, or potential for inadequate performance (e.g., clogging)
  -Factors (design, construction and operation) of contributing to satisfactory or unsatisfactory performance
  -Applicable corrective measures

- Gas and Emissions Control

  -Factors affecting gas generation, gas composition and emissions at strictly hazardous waste sites
  -Applicability of data and controls from co-disposal and municipal sites to strictly hazardous waste sites

- Research and Development Needs
- Miscellaneous

  -Regulatory considerations
  -Other data sources and contacts
  -Etc.

TABLE 1. COMPANIES AND ORGANIZATIONS WITH WHOM TECHNICAL DISCUSSIONS WERE HELD

Technical Discussion No.	Date	Individual(s), Company/Organization and Address
1	4/13/84	R. Huitric, J. Lu San. Districts of Los Angeles Co. 1955 Workman Mill Rd. Whittier, CA 90607 (213) 699-7411
2	4/16/84	Larry Well CH2M-Hill 2300 N.W. Walnut Blvd. Corvallis, OR 97339 (503) 752-4271
3	4/17/84	Mike Kennedy CH2M-Hill 2020 S.W. 4th Avenue Portland, OR 97201 (503) 224-9190
4	4/23/84	J. Johnson, W. Lockman, R.Lofy Lockman and Associates 249 E. Pomona Blvd. Monterey Park, CA 91754 (213) 724-0250
5	4/24/84	R. Beyer, W. Bonta, L. Martino, R. Rosnick Hazardous Waste Management Div. Waste Management Administration 201 West Preston Street Baltimore, MD 21201 (301) 383-5736
6	4/25/84	D.R. Foster Maryland Environmental Service 60 West Street Annapolis, MD 21401 (301) 269-3666

(Continued)

TABLE 1. (Continued)

Technical Discussion No.	Date	Individuals(s), Company/Organization and Address
7	4/26/84	J. Bross, G. Elliot Duffield Associates, Inc 5350 Limestone Road Wilmington, DE 19808 (302) 239-6634
8	4/30/84	John Reinhardt Residuals Management Technology 1406 East Washington Ave., #124 Madison, WI 53701 (608) 255-2134
9	5/01/84	M. Gordon, P. Kmet, G. Mitchell Department of Natural Resources 101 S. Webster St. Madison, WI 53707 (608) 266-8804
10	5/02/84	R. Cooley, D. Kolberg, D. Viste Warzyn Engineering, Inc. 1409 Emil Street Madison, WI 53715 (608) 257-4848
11	5/22/84	Joe David, R. Koltuniak Black & Veatch Engineers-Architects 7315 Wisconsin Avenue, Suite 850N Bethesda, MD 20814 (301) 986-8980
12	5/23/84	E. Belmore, J.Coyle, M. Hans, F. Grabar NY Dept. of Environ. Conservation 600 Delaware Street Buffalo, NY 14202 (716) 847-4585
13	5/24/84	Site A

(Continued)

TABLE 1. (Continued)

Technical Discussion No.	Date	Individual(s), Company/Organization and Address
14	5/25/84	S. Arlotta Wehran Engineering 666 East Main Street Middletown, NY 10940 (914) 343-0660
15	6/29/84	F. Cope, J. Pacey, R. Van Heuit Emcon Associates 90 Archer Street San Jose, CA 95112 (408) 275-1444
16	7/10/84	L. Collings, J. Pena, W. Taylor Getty Synthetic Fuels, Inc. 2750 Signal Parkway Signal Hill Parkway Signal Hill, CA 90806 (213) 595-4964

SECTION 4

LEACHATE COLLECTION SYSTEMS

4.1 REGULATORY BACKGROUND AND SOME GENERAL CONSIDERATIONS

The land disposal regulations promulgated by the U.S. Environmental Protection Agency (EPA) in July 1982 as Interim Final regulations (40CFR 264.301) require the installation of leachate collection systems (LCS) for all newly constructed hazardous waste landfills. The purpose of the LCS is to intercept and remove the leachate from the landfill thereby preventing the build-up of leachate in the landfill and hence the stress on the liner. Leachate removal should thus prolong the liner life, reduce the potential for leachate migration and allow for treatment and disposal of the leachate under controlled conditions.

The interim regulations specify a maximum leachate head of 30 cm (1 ft) above the liner and direct the EPA Regional Administrators to specify, as part of the permitting process, design and operating conditions which would ensure that this maximum leachate head specification is not exceeded. The regulations also state that the LCS construction material (pipes) should be (a) of sufficient strength and thickness to prevent collapse under the pressures exerted by the overlying wastes, waste cover materials, and by any heavy equipment; and (b) chemically resistant to the wastes managed and expected leachate. Finally, the regulations state that the LCS must be designed and operated to function without clogging through the scheduled closure of the landfill.

Although EPA (3) and others (4-7) have provided some guidelines on design and construction of LCS (see Table 2 for EPA guidelines), very little information is available on the effectiveness of the suggested design and construction practices in preventing LCS clogging. These guidelines (e.g., the specifications for graded granular material or fabric filters) are largely based on experience from other fields (e.g., the general construction, agricultural drainage, and water well industries) and have not been verified in waste disposal applications. Indeed, there is very little feedback on the performance of LCS in few facilities which have utilized the state-of-the-art design. Accordingly, the actual or potential clogging of LCS and the extent of the problem appear at this time to be matters of conjecture rather than documented observations.

TABLE 2. EPA MINIMUM GUIDELINES FOR THE DESIGN OF LCS (3)

At least a 30 cm (12-inch) drainage layer with a hydraulic conductivity 1×10^{-3} cm/sec and a minimum slope of 2 percent

A graded granular or synthetic fabric filter above the drainage layer to prevent clogging, except in the case of secondary leachate detection, collection and removal systems that are in direct contact with the primary synthetic liner. If a granular filter is used , the grain size should meet the following criteria:

$$\frac{\text{D15 (Filter soil)}}{\text{D85 (Drainage layer)}} \leq 5$$

$$\frac{\text{D50 (filter soil)}}{\text{D50 (drainage layer)}} \leq 25$$

and

$$\frac{\text{D15 (filter soil)}}{\text{D15 (drainage layer)}} = 5\text{-}20$$

where:

D15 = grain size in millimeters, at which 15% of the filter soil used, by weight, is finer

D85 = grain size, in millimeters, at which 85% of the filter soil (or layer media) used, by weight, is finer

D50 = grain size, in millimeters, at which 15% of the filter soil used, by weight, is finer

A drainage tile system of appropriate size and spacing and a sump pump or other means to efficiently remove leachate

They are, nevertheless, of some concern to design engineers, owners and operators of landfills and regulatory agencies, as it is often difficult to readily ascertain the functioning of the LCS and remedial actions can be very expensive after a significant volume of waste has been deposited at a site. The concern over the performance of LCS has promoted certain state regulatory agencies (e.g., Wisconsin Department of Natural Resources--see T.D. No. 9[*]) to establish stringent requirements for LCS design and to require a demonstration of the workability of the cleanout feature of the system.

The objective of the LCS segment of the present study has been to provide a better definition of and the experience with clogging and to identify corrective measures applicable to the identified problems and areas requiring R & D. Since the discussion in this and subsequent sections refer to various components of LCS, a schematic of a typical LCS is shown in Figure 1. Figures 2 and 3 show, respectively, pipe configuration and sump cross section for LCS in a cell at a hazardous waste disposal landfill site. It should be noted that the design and the waste placement practice depicted in Figures 2 and 3 are for a particular site and are not typical of operating hazardous waste landfills.

4.2 PREVIOUS STUDIES

Under the sponsorship of the U.S. EPA, two studies were recently conducted by GCA Corporation (9) and by Arthur D. Little (ADL), Inc. to compile the relevant available information and to provide a better definition of the LCS clogging problems.

The GCA study resulted in a "white paper" for use by EPA in addressing the subject of LCS design in its Interim Final land disposal regulations. The paper drew together documented information on the clogging of agricultural drainage systems and water supply wells and assessed the potential for LCS clogging based on some theoretical considerations and inference from the experience with these other systems. Assuming that LCS failure due to clogging was a real possibility, the paper presented a theoretical discussion of the physical, chemical and biological factors which can contribute to such failure and of applicable preventive and corrective measures.

The ADL study extended the GCA study to include additional telephone interviews with landfill operators and an investigation of some cemented materials found in gravel around a drain at an EPA demonstration landfill in Boone County, KY, to determine

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[*] "T.D. No." references refer to the technical discussion summary reports presented in Appendix A.

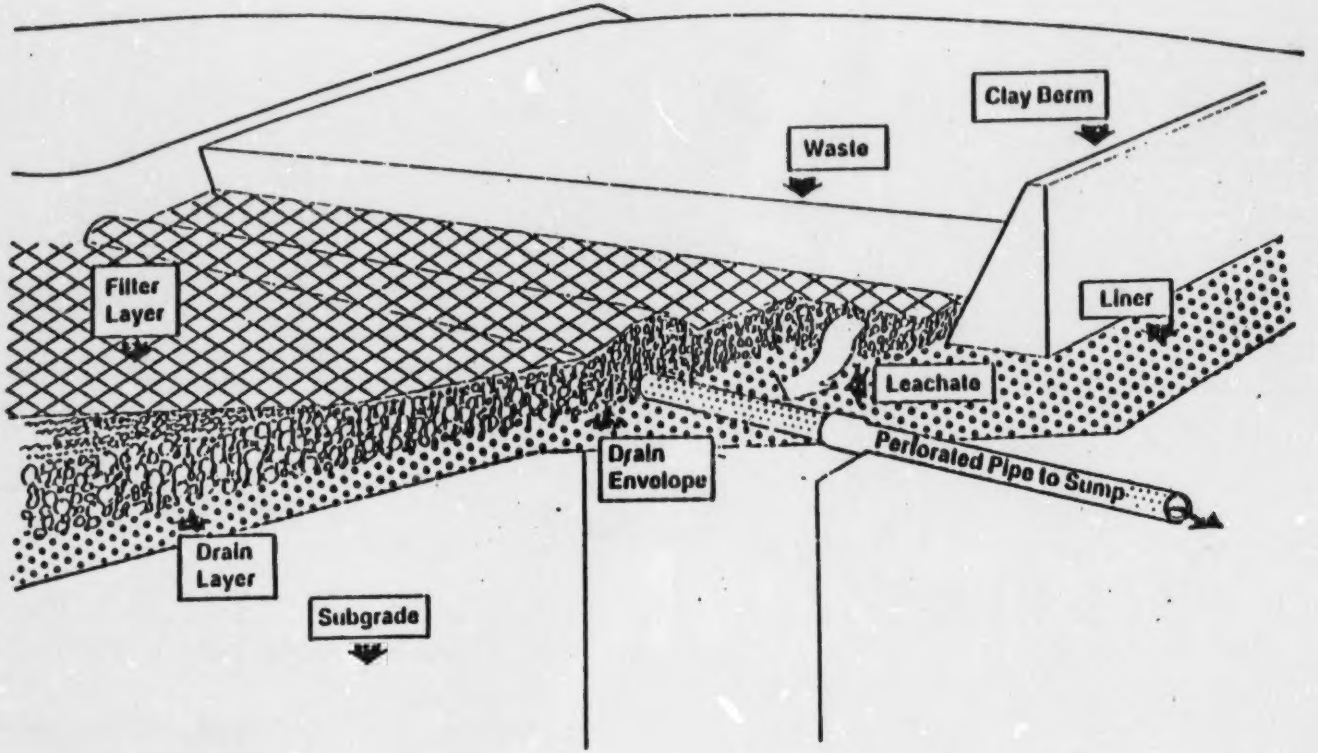
Clay Berm
Waste
Liner
Filter Layer
Leachate
Drain Envelope
Perforated Pipe to Sump
Drain Layer
Subgrade

Figure 1. Schematic of a typical leachate collection system (8)

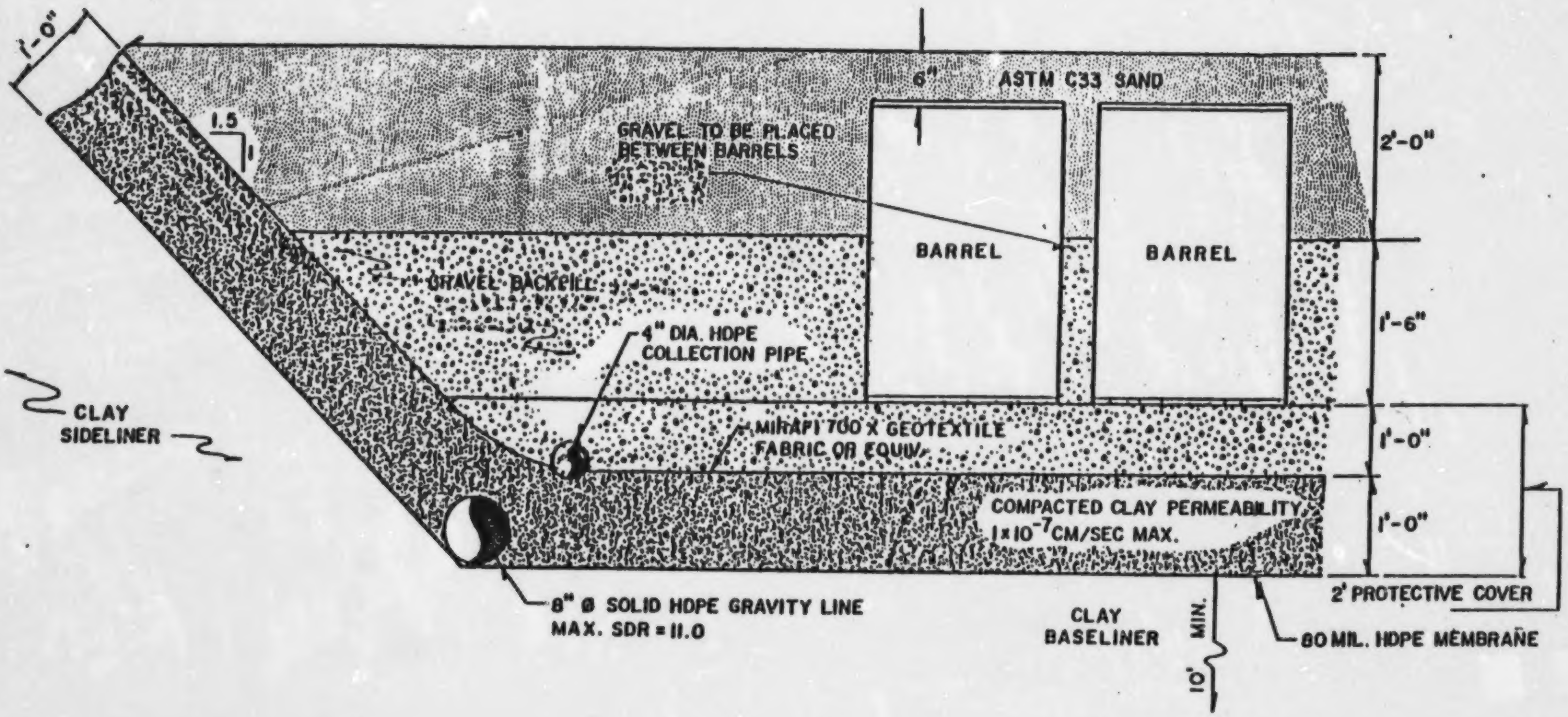
1'-0"
6"
ASTM C33 SAND
1.5
1
GRAVEL TO BE PLACED BETWEEN BARRELS
BARREL
BARREL
2'-0"
1'-6"
1'-0"
1'-0"
GRAVEL BACKFILL
4" DIA. HDPE COLLECTION PIPE
CLAY SIDELINER
MIRAFI 700 X GEOTEXTILE FABRIC OR EQUIV.
COMPACTED CLAY PERMEABILITY 1x10^-7 CM/SEC MAX.
8" Ø SOLID HDPE GRAVITY LINE MAX. SDR = 11.0
CLAY BASELINER
10' MIN.
2' PROTECTIVE COVER
80 MIL. HDPE MEMBRANE

Figure 2. Typical pipe configuration for LCS in a cell at a hazardous waste landfill (T.D. No. 13)

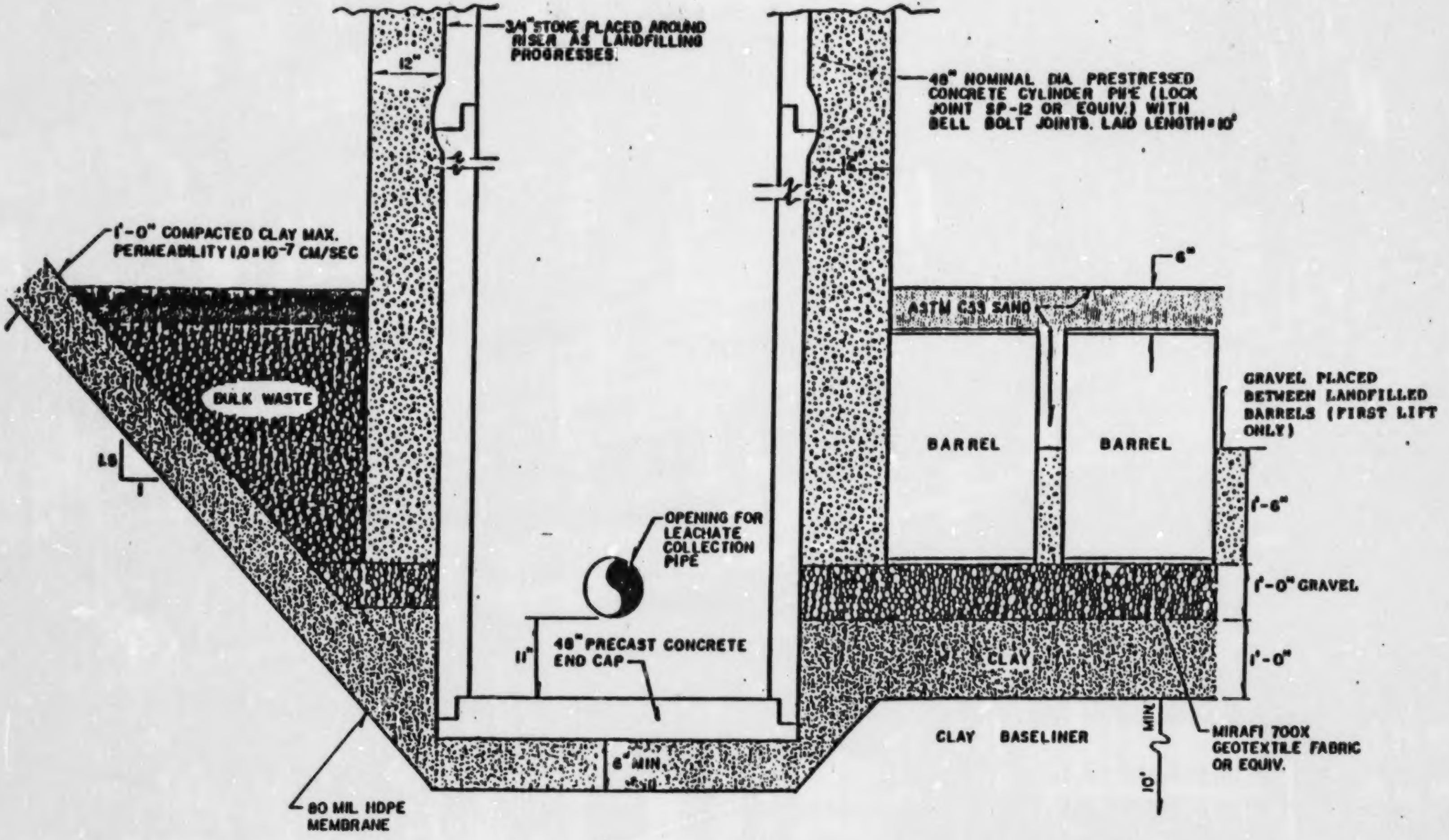
3/4" STONE PLACED AROUND RISER AS LANDFILLING PROGRESSES.
12"
48" NOMINAL DIA. PRESTRESSED CONCRETE CYLINDER PIPE (LOCK JOINT SP-12 OR EQUIV.) WITH BELL BOLT JOINTS. LAID LENGTH=10'
12"
1'-0" COMPACTED CLAY MAX. PERMEABILITY 1.0×10-7 CM/SEC
6"
ASTM C33 SAND
BULK WASTE
GRAVEL PLACED BETWEEN LANDFILLED BARRELS (FIRST LIFT ONLY)
BARREL
BARREL
1.5
1
OPENING FOR LEACHATE COLLECTION PIPE
1'-6"
1'-0" GRAVEL
11"
48" PRECAST CONCRETE END CAP
CLAY
1'-0"
6" MIN.
CLAY BASELINER
MIN.
10'
MIRAFI 700X GEOTEXTILE FABRIC OR EQUIV.
80 MIL HDPE MEMBRANE

Figure 3. A cross section of leachate collection sump for LCS at a hazardous waste landfill (T.D. No. 13)

causual mechanisms. The ADL study also reviewed the possible mechanisms of clogging and discussed potentially applicable preventive and remedial measures. A summary of the clogging mechanisms identified is presented in Table 3.

4.3 PROBLEM OVERVIEW

There is currently limited information on the extent of LCS clogging experience in full-scale facilities. This lack of information stems from (a) the relatively young age of LCS in current service, (b) progression and continuous advancements in LCS design and operating practices, (c) lack of a standard definition of what constitutes clogging and of monitoring systems to detect problem, (d) a lack of concern on the part of many operators who have traditionally viewed the clogging not as a major problem but as a minor and manageable nuisance and their general reluctance to openly discuss their experience (if any) with LCS clogging, and (e) the general perception by design engineers that the extensive redundancies which are incorporated in the latest designs render any potential clogging a localized problem and inconsequential to the overall performance of LCS.

The actual experience with engineered sites featuring LCS is very limited (T.D. Nos. 3, 8 and 15). For example, in Wisconsin, which has been a leader in incorporating the state-of-the-art in design and regulations, the first generation engineered sites went into service only in about mid-1970s and it was not till about 1980 when some operating data became available for some of these sites (T.D. No.8). Even during such a short time span, there have been considerable and continuous advances in LCS system design and operating practices (T.D. No. 14) that collection of extensive performance data for older systems have not been apparently justified. (This progression of design and changes in operating practice which incorporate lessons learned from previous experiences, is best illustrated by the cell-by-cell operation at certain hazardous waste management facilities--see T.D. Nos. 12, 13 and 14.)

There is currently no firm basis/criteria for determining whether a leachate collection system is experiencing clogging (T.D. Nos. 3 and 8). The water budget method of determining leachate flow for design purposes may be inaccurate as a basis for determining the extent of clogging. Use of head wells for direct observation of leachate levels is a preferred method and the one which is now required in Wisconsin (T.D. Nos. 8 and 9). The design requirements for a head well leachate level monitoring system from the standpoint of number and locations of wells needed to produce reliable data, however, have not been established. Traditionally, a very significant reduction in the normal leachate flow or the absence of a noticeable increase in flow following a major storm has generally been assumed to

TABLE 3. SUMMARY OF CLOGGING MECHANISMS (8,9)

PHYSICAL MECHANISMS

1) Inadequate carrying capacity related to inadequate design:

   - -Inadequate pipe spacing, slope, or diameter
   - -Insufficient slot area
   - -Undersized pump or sump outlet diameter
   - -Improper or insufficient drainage media

2) Structural failure or collapse caused by mechanical crushing or displacement, and possibly aggravated by physical deterioration of drainage materials:

   - -Compaction and trafficking over drainage materials during installation
   - -Compaction of waste (loading) during normal operation
   - -Consolidation settlement of waste and underlying soil
   - -Physical deterioration caused by pH extremes, oxidizing (metal pipes) or organic solvents (plastic pipes)
   - -Penetration of drains by refuse

3) Sedimentation or trapping of solids (arising from the waste, daily cover cap, envelope, or filter materials) in pipe or sump due to:

   - -Incorrectly selected grain size distribution
   - -Improper pipe slot size
   - -Piping of the envelope due to hydraulic failure or scouring
   - -Low flow due to shallow pipe slope, installation of impermeable cover, source control

CHEMICAL MECHANISMS

1) Formation of insoluble precipitates (calcium carbonate, manganese carbonates, sulfides, and silicates) under basic, neutral, or slightly acidic conditions which deposit on drainage materials by trapping or evaporation during dry periods.

(Continued)

TABLE 3. (Continued)

BIOCHEMICAL AND BIOLOGICAL MECHANISMS

1) Ferric hydroxide or ferric sulfide precipitate formation as a result of anaerobic and then aerobic bacterial action leading to a mix of biological slime and precipitates called ochre. Blocked drainage systems can result depending on:

   - presence of iron and/or sulfate reducing bacteria, ferric ions (from soils or waste) and sulfates

   - pH conditions and redox potential

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indicate LCS malfunctioning. The former criterion requires historical flow data (T.D. No 3), which is not generally available for most sites, and the latter criterion is qualitative and will not detect clogging unless it is very drastic and advanced. Accordingly, the landfill operators generally do not have a solid basis to determine how well or poorly an LCS is actually performing.

Nearly all design engineers with whom technical discussions were held in the present study (see, for example, T.D. Nos. 4, 8, 10, 14 and 15) saw little potential for any clogging of consequence with the new LCS designs, because of the considerable built-in redundancies. These redundancies relate to (a) the oversizing of the pipes, (b) availability of alternate flow routes (i.e.,other laterals and the drainage trench/blanket) in the event that one or more laterals become plugged, and (c) provisions for cleaning access to pipes. Much of the documented problems with the existing LCS relate to older systems (primarily municipal or co-disposal sites), which lacked sophisticated designs, did not incorporate design redundancies, and in many cases consisted merely of simple toe drains (T.D. No. 15). With the reference and guidance documents which have been made available to the designers in recent years (e.g., the EPA Technical Resource Documents), the opportunities for making mistakes are far less today than they were previously when the older systems were being designed (T.D. No. 15). Some designers feel that with the state-of-the-art design and operating practice, a dry landfill is an achievable goal (T.D. No. 14), and LCS in some landfills in a dry climate have been installed primarily as a precautionary measure rather than to actually remove any leachate (T.D. No. 1).

Some designers (T.D. No. 10) pointed out that getting the leachate to drain through the refuse mass and reach the LCS represents a much greater design and operation challenge than getting the leachate to exit through the underdrain once it reaches it (see also T.D. No. 9 for actual experience with leachate perching in landfills). The differences between the permeabilities of the waste and the LCS drainage material has been taken advantage of in a new "air gap" design concept where the leachate head on the liner is limited to that in the drainage layer which is made independent of the actual head in the fill which can be possibly much higher than that in the drainage layer (T.D. No. 14).

Design engineers who were familiar with the agricultural drainage systems thought that it would be inappropriate to draw conclusions as to the expected performance and service life of the LCS based on experience with the agricultural drainage systems (T.D. Nos. 8, 10 and 15), because of the differences in design, construction and maintenance practices for the two systems. For example, tile pipes used in agricultural drainage systems are constructed with open joints, the construction receives little or no QA/QC, and there is no subsequent maintenance (cleaning) and repair program for these systems.

Given the above considerations, it is not surprising that the present study did not identify LCS clogging as a problem of major concern. For the sample of sites represented by the owners, designers, state regulatory agencies and a commercial sewer inspection and cleaning company with whom technical discussions were held, LCS clogging was a problem of major concern at only one site (a unique co-disposal facility handling a significant volume of liquid industrial wastes) (T.D. No. 4), with two hazardous waste facilities reporting some previous experience with minor siltation in the LCS standpipes (T.D. No. 12). The inspection of a section of LCS at two municipal landfills in Wisconsin indicated no evidence of clogging or deterioration after some 10 years of actual service; except for some discoloration, the gravel in the trench was very clean and appeared intact (T.D. No. 10). Biological growth has been noted in and around the LCS pipes at some sites in Wisconsin (10). The annual jet cleaning of the lines, however, has been effective in dislodging the biological growth as well as silt accumulation which has been noted at certain sites (10). At some older municipal sites where crushed limestone has been used as the bedding material in the LCS trenches, reaction with the acidic leachate has resulted in the cementation of the drainage material into solid blocks (10). In newer designs, the limestone has been replaced with inert "washed stone" (10).

The reported experiences with LCS are discussed in the following section.

4.4 OPERATING FACTORS AFFECTING AND THE EXPERIENCE WITH THE PERFORMANCE OF LEACHATE COLLECTION SYSTEMS

With the latest design practices, the proper functioning of LCS appears to be a case-specific problem depending to a large extent on the type of waste handled, waste placement method, the kind of material used for cover and cover placement method.

Accepting a significant volume of liquid wastes, sludges with considerable amounts of fines and wastes with low permeabilities have been identified as causes of poor LCS functioning at a number of sites. At one hazardous-municipal co-disposal site (T.D. No. 4) where about 30% of the waste handled is comprised of liquid industrial wastes, the clogging of the LCS (including the sand and gravel) has been a recurring problem. At this site the clogging, which is due to chemical deposition and solidification, is very nonsystematic and appears to be related to the variations in the type of waste handled and hence in the leachate characteristics.

Some siltation has been noted at the bottom of the leachate collection standpipes (sumps) in older cell designs employed at two hazardous waste facilities in New York (T.D. No. 12). The problem has been mostly in the cells dedicated to heavy metal sludges and has been attributed to the passage of fines through the gravel drainage into the LCS collection pipes as well as possibly through the joints of the standpipes. At a facility in Wisconsin, where the drainage envelope also consisted of gravel only with no sand layer filter media on top of gravel and where paper mill sludges were included in the first few lifts, leachate perching and mounding were observed and were attributed in part to a blinding of the gravel envelope by the fine particles in the paper mill sludge which penetrated it (T.D. No. 9).

Inadequate drainage through the waste and/or materials used as intermediate cover has resulted in leachate perching and excessive mounding at some sites. At a hazardous waste site in New York (T.D. No. 12), some leachate perching which was observed was attributed to the use of water treatment sludges as intermediate cover. Similar perching phenomena have been observed at other sites where shredded refuse and/or paper mill sludges were accepted and where low permeability materials (such as shredded refuse or clayey soils) were used as intermediate cover (T.D. Nos. 9, 10, 12). Because of their relatively low permeability, these wastes and intermediate covers can act as barriers to leachate (and gas) movement. The buildup of leachate and of high gas pressures (T.D. No. 9) have led to some documented cases of "leachate geysers" in landfills.

At many sites the pumping of leachate from sumps is on an infrequent basis. This at times can result in excessive leachate accumulation (long residence time) in the sumps and very high (perhaps as much as 10 to 20 ft) heads in the landfill. A very long residence time in the sumps can result in particle settling and silt accumulation (T.D. Nos. 12 and 13). Automatic leachate pumping whereby the leachate level in the sumps will always be maintained lower than a certain level has been successfully used in some hazardous waste sites (T.D. Nos. 12, 13, 14) to increase drainage and to reduce potential for long residence time in the sump.

4.5 PREVENTIVE AND CORRECTIVE MEASURES

As noted previously, there has been little opportunity for LCS-related corrective action at RCRA-designed hazardous waste landfills. Some corrective actions which have been used in some older co-disposal sites, and which may be applicable to hazardous waste sites, include the following:

- Use of gravel trenches or pipes to intercept leachate (T.D. Nos. 6, 10 and 15).
- Drilling caissons in landfills and pumping out the perched leachate (T.D. Nos 5, 10 and 15).
- Replacing sections of the collection system (where the depth of the overlying waste is not significant) (T.D. Nos. 4 and 15).

Indeed, at one site where LCS clogging has been a recurring problem (T.D. No. 4), the corrective measure used has been that of replacing various affected sections of LCS. The reparative measures which have been considered and/or are being undertaken at one site experiencing leachate perching and poor drainage include drilling caissons to various depths within the fill and constructing a gravel "trench" all the way to the bottom of the fill along the inside periphery of the site (T.D. No.10).

The corrective actions, or in general the retrofitting of older sites with leachate collection systems can be very costly, especially for large landfills and, in the case of hazardous waste sites, can present considerable risk and safety hazards. Based on the information collected in the present study, the problems associated with the functioning of LCS in hazardous waste (or other types of) landfills can best be addressed through preventive means involving a combination of good design and appropriate operating practices. Failure to implement suitable preventive measures can lead to major problems for which practical corrective measures may be prohibitively expensive. For example, at the present time there is no practical corrective measure (short of total system replacement) for restoring the hydraulic capacity of the LCS drainage blanket if it becomes totally ineffective due to sedimentation and chemical deposition (T.D. Nos. 3, 5 and 7). Excavation in hazardous waste landfills can be very dangerous and sometimes exceedingly difficult (T.D. Nos. 3, 5 and 6).

As long as the leachate collection and conveyance pipes are provided with adequate cleanout accesses, restriction of flow due to simple siltation and accumulation of chemical/biological deposits should be correctable (and have been corrected) by use of conventional sewer cleaning techniques. On a number of occasions, the expertise and services of the sewer cleaners have indeed been called upon to restore the capacity of clogged leachate lines or to provide preventive maintenance services (see Section 4.5.3). The Water Pollution Control Federation has published a manual of practice on operation and maintenance of wastewater control systems (11) which provides detailed discussions of the state-of-the-art sewer inspection and cleaning techniques and equipment, including safety hazards and measures for preventing explosions and injuries from oxygen deficiency and obnoxious gases. There are many devices which can be used to detect the presence of flammable vapors and toxic gases. Ref. 11 lists some 55 flammable and toxic gases which can be tested for by portable testing equipment.

A summary of sewer inspection and cleaning methods is presented in Table 4. Based on the reported experience (10, 12 and T.D. No. 7), jetting appears to be very effective and most appropriate for cleaning LCS lines. Although there is no reported experience with the use of television inspection for LCS lines, the technique was successfully employed recently to obtain the profile of in-place waste at a co-disposal site in Wisconsin where caissons were being drilled for the removal of perched leachate (10). According to a commercial sewer cleaning company which has provided LCS cleaning service in Wisconsin and several other states in the region (12), as long as LCS lines are properly designed (i.e., lines are 6-in. or greater in diameter and cleanout accesses are provided at strategic locations including at places where there is a change in the direction of flow), the cleaning of the LCS lines does not present any technical problem which can not be handled with the available equipment and procedures. Due to the nature of waste and often the unknown environment, however, the personnel may have to exercise more caution when servicing LCS lines.

Use of some of the methods listed in Table 4 for cleaning and restoring the hydraulic capacity of contaminated sewer lines located downgradient of hazardous waste disposal sites are discussed in the Handbook for Remedial Action at Waste Disposal Sites (6).

4.5.1 Design Considerations

Design considerations for improving the functioning of a

TABLE 4. SEWER INSPECTION AND CLEANING METHODS (11)

Method	Description	Remarks
Closed Circuit Television Inspection	While the camera skid is pulled between two manholes, the TV camera scans the area in front of the skid and transmits it to monitor screen. A tag line is also attached to the rear of the camera assembly making it possible to back up for viewing a problem or to retrieve the camera if it is impossible to pull it completely through the line.	Most effective method of determining nature of internal problem. Can be used on all pipes down to 4 in. diameter. Most municipalities own and operate these equipment. Some contract out for service.
Power Rodding	The power equipment applies torque to the rod as it is pushed through the line, rotating the cleaning device.	Fairly efficient in lines up to 12 in. Used for routine preventive maintenance breaking up grease deposits, cutting roots, threading cables for bucket machine or TV inspection equipment.
Balling	Hydraulic cleaning a pipe by using the pressure of a water head to create high velocity water flow around the ball. The ball is restrained by a rope or cable while the water washes past it at high velocity.	Very effective for removing deposits of settled inorganic material (grit) and grease buildup inside the line. The material removed by balling should be caught and removed at the downstream manhole.
Flushing	Hydraulic cleaning involving introduction of a heavy flow of water into the line at a manhole.	Effective for removal of floatables and some sand and grit but is not very effective for removal of heavy solids. Less frequently used since introduction of the high-pressure water jet cleaners (see below).
Jetting	Hydraulic cleaning method whereby high velocity streams of water are directed against the pipe walls at various angles. Jetting equipment consists of a water supply tank that holds usually 1000 gal. or more, a high-pressure water pump, an auxiliary engine, a powered drum reel holding at least 1500 ft of 1-in. inside diameter hose on a reel having speed and direction controls, a variety of interchangeable nozzles, and necessary tools such as hose rollers and guides.	Very effective in cleaning small diameter, low-flow pipes and to clean stoppage caused by debris. Desirable to remove loosened material with vacuum.

(Continued)

TABLE 4. (Continued)

Method	Description	Remarks
Scooter	Hydraulic cleaning method whereby the pressure of water behind the shield of a scooter moves the scooter downstream and the water forces past the shield rim and scours the pipe walls as with the balling method.	Requires tank truck of 1000 to 2000 gal. capacity. Efficient cleaning tool and effective in removing blockage. Effective in lines up to 95 in.; good preventive maintenance.
Kites, Bags, Tires and Poly Pigs	Devices used to hydraulically clean large pipes in a manner similar to balling. Water pressure moves these devices against the tension of their restraining lines.	Same as for scooter.
Bucket Machine	A mechanical cleaning device effective in partially removing large deposits of silts, sand, gravel, and some types of solid waste. When the bucket is pulled in the opposite direction by the working machine, the jaws are forced closed, and any material retained in the bucket is pulled out through the manhole.	Used to remove debris from a break or accumulation that cannot be cleared by hydraulic cleaning. Slow and very costly; recommended for special conditions only.

facility from the standpoint of leachate management can be broadly grouped into three somewhat overlapping categories: Those aimed at reducing the potential for leachate generation; those aimed at providing better leachate control; and those aimed at reducing impacts on LCS and the consequences of malfunctions and failures. Examples of design considerations in the first category are (a) use of "progressive design" (T.D. No. 14) where a cell-by-cell design approach would limit the size of an active cell/area and hence the amount of leachate due to water inflow prior to closure; and (b) proper design and maintenance of cover to minimize infiltration. Progressive design also enables some experimentation to incorporate design modifications based on experience from preceeding fill operations or general technological advances. Improved leachate management capabilities can be achieved through designs which allow for waste segregation and separate disposal by waste type category. Incorporating redundancies in design (e.g., oversizing of laterals), use of automatic level-controlled leachate pumping systems and use of geotextiles as separators to prevent or reduce penetration of drainage blanket by soil or waste particles are two examples of design considerations for reducing the potential adverse impact on LCS functioning and the consequences of partial LCS clogging.

The above-mentioned and other related design considerations which reflect the experience and perspectives of those with whom discussions were held in the present study are summarized in Table 5. Guides and recommendations on detailed design of landfills and its components are discussed elsewhere and will not be addressed here. It should, however, be pointed out that the detailed design (and also often the general design approach--see T.D. Nos. 1, 4, and 8) have to take into account site- and situation-specific conditions and must be tailored to the specific job requirements.

4.5.2 Construction and QA/QC Considerations

Use of proper construction techniques and QA/QC procedures are very important in avoiding subsequent LCS malfunction due to poor construction methods and deviations from specifications which were not caught because of inadequate inspection. Construction- and QA/QC-related considerations have been discussed in several recent publications (1, 2, 4, 13). Some relevant experiences which were conveyed to this study by the individuals with whom technical discussions were held follow.

A well-designed chemical landfill in Michigan is an example of how poor construction technique and QA/QC oversight can result in system clogging and subsequent leakage from connections (14). While excavating to install leachate sumps for new cells, liquid began to flow out in an excavated gravel area where leachate and

TABLE 5. DESIGN CONSIDERATIONS FOR IMPROVING SITE PERFORMANCE FROM THE STANDPOINT OF LEACHATE MANAGEMENT

Considerations and References	Objective	Description/Comment
Progressive design (T.D. No. 14)	-More rapid achievement of a "dry" landfill operation -Incorporation of experience from preceding designs and the technological advances -Limiting risk to small areas/units and implementation of corrective actions less costly	-Cell-by-cell design thereby limiting the size of the active cell/area to that which can be filled and closed within 1-2 yrs. The leachate to be pumped out thus restricted to water entering site during short active life
State-of-the-art cover design and subsurface water interception (T.D. Nos. 1, 2, 13, 14)	-Minimize infiltration	-Cover design to allow little or no water infiltration to a closed cell, thereby limiting the leachate to be pumped out to water entering site during waste placement -Use of subsurface drains to intercept perched or spring water and proper surface drainage to divert/intercept surface runoff
Multiple cell design for segregated waste disposal (T.D. Nos. 1, 2, 13, 14)	-Provide for better operating control	-Dedicating specific landfill cells/areas to specific wastes or waste categories (e.g., heavy metal sludges) and tailoring cell design and operation to waste-specific properties requirements
Incorporation of design redundancies (T.D. Nos. 7, 8, 10, 14, 15)	-Provide for adequate safety factor and contingencies	-Oversizing and closer spacing of LCS pipes -Use of drainage media (e.g., appropriate gradation of conventional sand and gravel filter which would allow rapid drainage and prevent head build-up and yet effectively retain waste particles without plugging -Use of drainage blanket (in preference to drainage trench) to provide positive connection across the entire base of the landfill -Providing adequate number of cleanout accesses (i.e., one for every 1000 ft of pipe) and avoiding sharp bends at pipe connections -Placing leachate riser pipes in the landfill wall rather than in the fill or on the surface of the side wall, to avoid potential damage due to waste load and movement -Placing gravel or similar material around standpipes in a vertical column extending to the top, to promote leachate drainage

(Continued)

TABLE 5. (Continued)

Considerations and References	Objective	Description/Comment
Use of inert materials as drainage bed for LCS (10)	-Prevent reaction with the leachate	-Use of crushed limestone as bedding materials at some older sites had resulted in cementation and formation of solid blocks due to reaction with acidic leachate
Use of specially fabricated pipe connectors, sweep bends, and 6-in. or larger pipes and providing cleanout accesses at strategic locations (10, 12, T.D. Nos. 9, 15)	-To enable better access to pipes for maintenance purposes including use of TV camera for inspection	-Depending on specific job conditions, specially fabricated pipe connectors, use of slotted pipes (in preference to perforated pipes) and use of sweep bends instead of sharp bends at connections may promote better access to pipes or easier pipe maintenance
Equipping manholes and cleanouts with covers	-To prevent debris from entering lines	-Unless these openings are kept covered, debris and other wind-blown materials can enter lines and result in flow obstruction. This has been identified as a source of problem at several sites requiring line cleaning to restore hydraulic capacity
Traffic load on collection pipes (T.D. No. 9)	-To minimize potential for pipe collapse due to traffic load	-Site design (and operation) to eliminate traffic over collection pipes -Use of half or whole corrogated pipes where there is trafficking
Automatic leachate pumping (T.D. Nos. 9, 12, 13, 14)	-Prevent leachate head buildup in collection sump and in the landfill	-Use of level-activated leachate pumping system to maintain leachate level in collection sump at or below the invert of incoming collection pipe, thereby promoting drainage and minimizing opportunity for clogging -Providing high sump level alarms to signal system malfunction -Providing leachate head wells in the fill for direct observation of leachate head

(Continued)

TABLE 5. (Continued)

Considerations and References	Objective	Description/Comment
Combining leachates from various cells vs. separate pumping	-Reduce cost and pump maintenance (combined pumping) -provides better controls (separate pumping)	-Assuming compatability, leachate from various cells can be directed to a common sump prior to pumping -Design for combined pumping can incorporate contingency provisions for leachate segregation and separate pumping if necessary
Use of geotextiles (T.D. Nos. 9, 11, 12, 14, 15)	-As a separator or filter to prevent LCS siltation	-Using geotextiles to envelope the granular material in the drainage trench or as a separator between the clay liner (or clay protective liner for FML) and gravel drainage blanket to prevent siltation by waste particle or soil from trench walls or liner -Some designers and regulatory agencies do not recommend use of geotextile as a filter medium in hazardous waste sites due to lack of previous experience
Freeze protection of pipes (T.D. No. 12)	-To prevent flow disruption due to winter freezing in cold climates	-Use of underground pumps for leachate removal from sumps and conveyance to treatment/disposal centers -Locating conveyance pipes in sufficient depth and designing them for gravity flow
Suitable slope and protective cover (T.D. No. 9)	-To prevent erosion washing of clay from side slopes	-Use of suitable side slopes (at least 3H:1V) and placement of protective cover (e.g., sand layer) on landfill side slopes to prevent erosion washing of of clay, some of which might find its way into and clog LCS

underliner collection sewer lines from the existing cells had been terminated and capped during the original installation. A 13-ft head build-up was noted in one of the manholes along the collection line whereas a second manhole immediately downstream had only about one inch of water. This indicated a possible blockage in the the connecting line between the two manholes. While preparing to enter the downstream manhole with a TV camera to determine the nature and location of the obstruction, workers pulled a 6-ft section of an 8-in. polyethylene pipe from this manhole and water began to flow at a substantial rate. Apparently this pipe had wedged into the leachate collection line at an angle just right to cut off almost all flow through this manhole.

To avoid damage to the LCS pipes during construction and initial waste placement, the state of Wisconsin has required use of half or whole corrugated pipes to cover trenches where there is trafficking (T.D. No. 9). This requirement, however, has only been partially effective as the traffic path constantly changes as the operation proceeds. Site design to eliminate traffic over the collection pipes is believed to be a more effective approach.

To provide for early detection of construction-related damages and timely implementation of corrective measures, the state of Wisconsin requires that, as a condition for obtaining an operating permit, the site owner/operator demonstrates ability to clean all leachate collection lines (T.D. No. 9). The test demonstration of a water jet cleanout system at one site resulted in the discovery of a broken pipe which was then replaced (9). The state also recommends that the lines be flushed after the first lift (T.D. No. 9).

4.5.3 OPERATING CONSIDERATIONS

Operating practices which improve the functioning of a facility from the standpoint of leachate management and impact on LCS primarily relate to source control (i.e. type of waste allowed in a landfill), waste placement method, type of material used as intermediate cover and cover placement.

Not accepting liquid wastes in landfills (or solidifying such wastes or mixing them with absorbents prior to placement) will eliminate waste as a leachate source. Containment and subsequent removal of rainwater which enters the site during operation also reduces the liquid volume which would have to be subsequently pumped out as leachate. Any ponded rainwater is considered contaminated and, at one facility (T.D. No. 13) it is removed and sewered. Use of temporary domes and roofs to keep the rainwater out when the site is open has also been considered and experimented with. After site closure, cover maintenance is essential to minimizing infiltration through the cover.

It is generally believed that it would be more cost effective to prevent the rainwater from entering the site during operation than to provide for any subsequent leachate collection and treatment. One commercial site reportedly employed a mobile inflatable dome covering a cell area of approximately 300 ft by 600 ft for this purpose (15). Due to events not related to the disposal operation (apparently a power failure), this inflatable dome was seriously damaged by a storm during a time when it was not in operation and is apparently no longer functional. A similar cover dome concept has reportedly been used at another commercial hazardous waste LF (15).

The use of structural cover systems to prevent overflowing of SIs due to rain and snow has been evaluated for application to clean-up of uncontrolled hazardous waste sites (16). As long as the active LF cell/area is kept relatively small, some such structures may conceivably also be applicable to LFs. Three promising structural systems on the market today which could be used for this purpose, and which have been analyzed in Ref. 14 for applicability to SIs are the following:

- Pre-engineered steel framed building with roof cover made of metal skin over longitudinal purlins and the walls made of metal skin over girts.
- Pre-engineered aluminum framed structures which would use aluminum frame and a flame retarded fabric (see Figure 4).
- Air supported structures consisting of tension cables covered with a fabric liner which is held up by application of an internal pressure (see Figure 5).

The costs for SI application of pre-engineered steel framed buildings and air supported structures (including site preparation and erection) have been estimated at $10.25/sq ft and $5.47/sq ft, respectively (16). The cost of pre-engineered aluminum framed structures is a function of the span. "Budget" costs for this type of structure F.O.B. at the site have been reported as follows (16):

-spans 30 to 60 ft:	$ 9.90/sq ft
-spans 88.6 ft:	$10.90/sq ft
-spans 120 ft:	$16.90/sq ft

Since LCS clogging has been related to the characteristics of the wastes and of the resulting leachate (T.D. Nos. 4 and 9), source control can reduce potential for LCS clogging (as well as adverse impacts on the liner). Heavy metals, paper mill sludges and other wastes containing fine particles should thus be placed near top and definitely not in the first lift (T.D. No. 9). At hazardous waste management facilities handling largely drummed

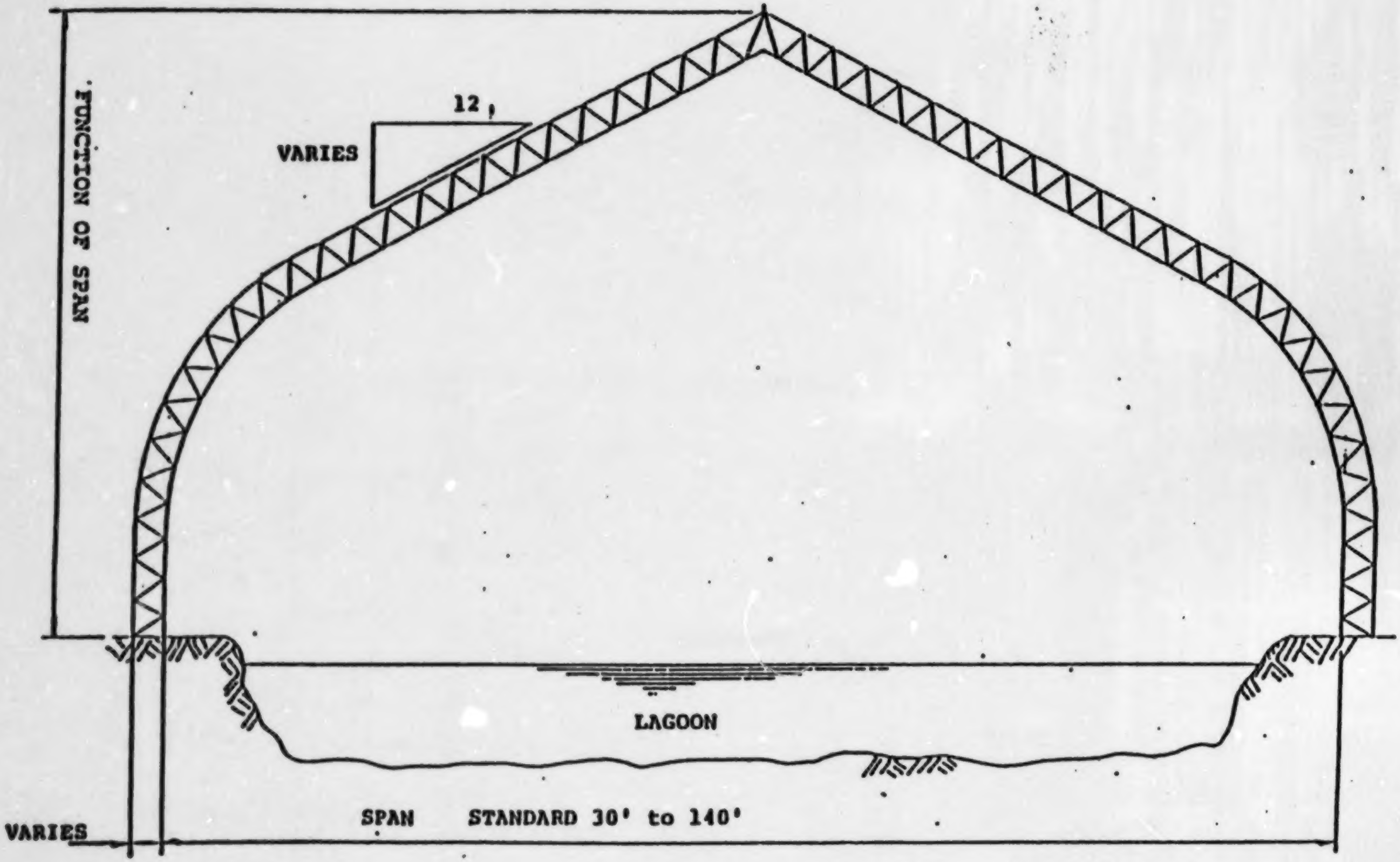
FUNCTION OF SPAN
12
VARIES
LAGOON
VARIES
SPAN
STANDARD 30' to 140'

Figure 4. Typical cross section of a pre-engineered aluminum framed cover structure for SIs (16)

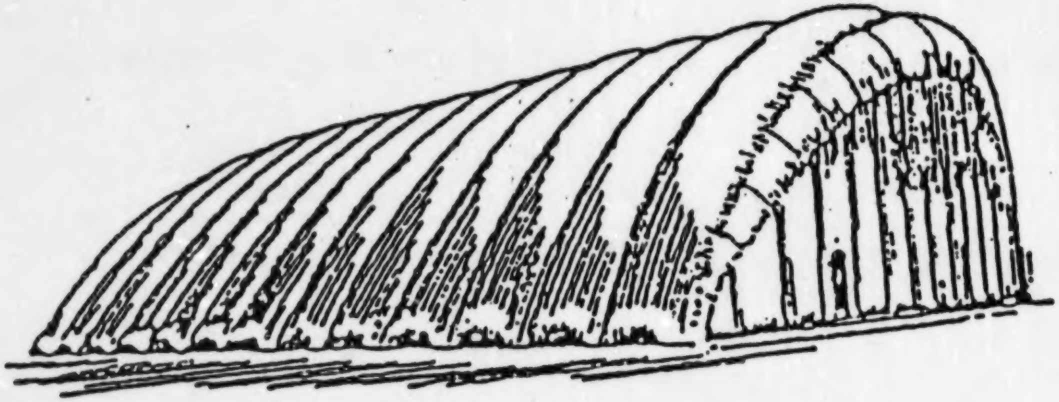

Figure 5. Sketch of an air supported structure (16)

wastes, placing drums containing wastes which would not readily mobilize (even if the drums fail) at the very bottom lift is an excellent approach to minimizing some of the leachate and LCS problems (T.D. No. 14). One facility uses lime waste and ferrous sulfate in the intermediate cover, and surrounds specific waste loads with such chemicals to effect immobilization and neutralization in the event of leakage from drums and the eventual corrosion of drums (T.D. No. 13).

The placement of low permeability wastes (e.g., shredded refuse and paper mill and water treatment sludges) over large contiguous areas or use of such wastes as well as clayey soil as intermediate cover can interfere with the downward movement of leachate and result in leachate perching and excessive mounding (T.D. Nos. 9, 10, 12). Low permeability waste should be blended with more permeable wastes as much as possible or placed in smaller isolated areas which are not connected (T.D. No. 9).

Landfill operators have generally used as daily cover whatever material is available to them at the site or nearby. This practice has resulted in leachate perching at a number of sites where clayey soils have been used as intermediate cover (T.D. Nos. 9, 10, 12). Since berms are usually wider than designed, the excess clay is removed before waste placement and often used as cover material. Because of these practices, operating permits for certain sites now specify the permeability of the cover material. For example, the permit for one site in New York stipulates the use of cover material with a permeability greater than 10^{-3} cm/sec in at least every fourth lift and greater than 10^{-4} cm/sec for all other lifts (T.D. No. 12). The state of Wisconsin Department of Natural Resources (T.D. No. 9) now advises against the use of clay or other low permeability materials as daily cover and recommends the use of sand as cover material at least for the first lift.

Stripping the previous day's cover is used at one co-disposal site to prevent leachate perching (T.D. No. 10). This practice, however, was considered inapplicable to hazardous waste sites handling drummed wastes given the likelihood for disturbing the carefully placed drums (T.D. No. 12).

As discussed previously, clogging of leachate collection pipes does not appear to be a problem of major concern to site owner/operators. Even though some sediments may deposit in LCS laterals and mains, the lines can be cleaned using the well-established sewer system cleaning technology. Periodic (e.g., once-a-year TV inspection of at least selected lines for clogging is considered by some designers (T.D. No. 8) as an element of a good maintenance program. Some designers have recommended cleaning of laterals and mains after the first six months of operation and inspection and cleaning of these lines every 2 to 3 years thereafter (T.D. No. 7). Video monitoring of pipes is a recommended inspection procedure for 6-in. diameter or larger pipes (the required equipment will not fit smaller pipes*) (T.D. No. 7). The pipes can be cleaned with rotorooters or hydroblasting (also referred to as jetting or jet rodding). Hydroblasting with jets is very effective and also cleans pipe perforations (10, 12 and T.D. No. 7). (See Table 4 for description of sewer cleaning methods.)

In Wisconsin, the requirement for inspection and cleaning of LCS laterals and mains is in addition to the requirement for monitoring leacnate head levels in the landfill to detect clogging problems. Annual cleaning is believed to result in flushing of any accumulations before they become too difficult to dislodge and hence a good preventive measure. Since there is no substantial difference between cleaning techniques for sewer lines and for leachate conveyance pipes, commercial sewer cleaning companies are generally called upon for service (10, 12 and T.D. No. 9). The cleaning cost is considered to be relatively small and, depending on the lines involved, the cleaning would require no more than two days' effort (T.D. No. 9). Sewer maintenance contractors are located in all major cities and typically charge $1000/day for video inspection and cleaning (which is equivalent to approximately 900 ft of pipe) (T.D. No. 7).

According to a commercial sewer cleaning company which has carried out LCS cleaning in Wisconsin and several other states in the region (12), many of the LCS flow obstruction problems can be avoided if the cleanouts, manholes and other opennings are kept capped to prevent wind blown debris from entering the system.

A summary of the operation-related leachate management problems and of applicable "non-design" preventive and corrective measures is presented in Table 6.

4.6 RESEARCH AND DEVELOPMENT NEEDS

For discussion purposes, the R & D needs identified by site owners and operators, designers and regulatory agencies are organized here under the categories of (a) developing improved basis for LCS design through studies reflective of actual conditions and/or through case studies of actual facilities, (b) investigation of novel design concepts and approaches, and (c)

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* Recent developments in closed circuit TV inspection includes one unit that can be used in 4-in. pipes (11). However, the cables for the smaller cameras are usually shorter (e.g., 150-ft for the camera for a 4-in. line compared to 1,000-ft for the camera for a 6-in. line (12).

TABLE 6. SUMMARY OF OPERATION-RELATED LEACHATE MANAGEMENT PROBLEMS AND APPLICABLE NON-DESIGN PREVENTIVE/CORRECTIVE MEASURES

Problems	Causes	Applicable Preventive/Corrective Measures
Excessive leachate	-Accepting liquid wastes	-Not allowing liquids in landfill -Placing sludges near top and definitely not in the first lift -solidifying liquid wastes or mixing them with absorbents prior to placement -surrounding specific load with absorbents
	-Infiltration	-Runoff diversion and containment and removal of rainwater entering active site -Use of temporary domes and roofs during operation -Use as temporary cover in lieu of soil for daily cover -Proper cover maintenance after closure -Removal of ponded rainwater during active life
Leachate perching	-Improper handling of low permeability wastes	-Source control (pretreating or not accepting troublesome wastes) -Placing troublesome waste (shredded refuse, paper mill sludges, etc.) near top and not in the first lift and in isolated areas rather than in continuous sections
	-Use of low permeability material as intermediate cover	-Not using clayey soils or low permeability wastes as intermediate cover -Using sand or other permeable material as intermediate cover (at least in the first lift) -Breaking the previous day's cover in the active filling area
LCS clogging	-Clogging of drainage material by fine particles and precipitates	-Source control (pretreating or not accepting troublesome waste or placing wastes such as metal sludge) near top and not in first lift -Replacement of drainage material
	-Clogging of pipes due to siltation, chemical and biological deposition and wind-blown debris entering lines when the openings are not kept capped	-Preventive maintenance (e.g., annual cleaning) using conventional sewer cleaning techniques -Replacement of pipes -Use of gravel trenches to intercept leachate -Drilling caissons in landfills and pumping out the perched leachate -Keeping cleanouts and manholes capped at all times
Collapse of drainage pipe	-Excessive traffic load	-Use of half or whole corrogated pipes to cover trenches where there is trafficking -Reroute traffic (or design site) so as to avoid traffic over collection pipes -Replacement of broken pipes (when discovered early)

miscellaneous studies. The technical discussions presented in Appendix A and referenced in the following discussion should be consulted for elaboration.

4.6.1 Developing Improved Basis for Design

As noted previously, at the present time there is little hard data on the long-term performance of LCS in full-scale facilities. Because some systems have now been in service for a number of years, it should be possible to obtain somewhat longer-term performance data for these systems so that the performance can be correlated with the designs actually employed. Case studies of LCS performance in full-scale facilities and long-term parametric studies at full-scale sites reflecting the actual operating practices and conditions were thus recommended by a number of designers (T.D. Nos. 4, 8, 10, 11, 14). In some instances, the evaluation of LCS performance may necessitate actually digging out sections of the system for direct observation. Pilot scale studies using real wastes can provide some performance data, although the results would not be as reliable. Case studies and full-scale or pilot-scale long-term parametric studies can provide information on or evaluate the following:

- Site/system performance versus design, construction and operating factors (T.D. No. 10).
- Permeability of various wastes relative to that of the drainage envelope/blanket (T.D. Nos. 10, 12, 13 and 14); considerable cost savings and improvements in design can result if LCS can be tailor-designed to handle specific waste type/placement practices (T.D. No. 14).
- Number and location of leachate monitoring head wells necessary to provide reliable information on LCS performance.
- Longevity of plastic pipes (T.D. No. 8) and geotextiles (T.D. Nos. 2, 9) in the harsh landfill/leachate environment and effectiveness/suitability of geotextiles as filter media in LCS applications (T.D. Nos. 12, 14 and 15).
- Applicability of standard civil engineering design curves and equations for pipe sizing to the unique conditions of LCS (i.e., small pipes in relatively narrow trenches and often subjected to high waste loads) (T.D. No. 10).
- Applicability of sewer design, construction and maintenance methods to LCS for hazardous landfills (T.D. No. 3).
- Geographic and local conditions which necessitate (a) differences in site design and flexibility in regulatory

requirements (T.D. No. 4), and (b) greater uniformity among regulatory requirements and enforcement policies of states with similar environmental setting (T.D. No. 10).

4.6.2 Investigation of Novel Design Concepts and Approaches

Evaluation of design innovations is considered by many designers as a very important area of R & D with potential for significant economic and environmental benefits. Some designers (T.D. No. 10) even suggest promotion and demonstration of new design approaches through government financial support for projects featuring design innovations.

Three cited examples of possible design innovations specifically relating to LCS are (a) provisions which would enable draining of the entire LCS trench/blanket and not merely the embedded pipe, (b) improving leachate drainage by extending the drainage blanket to also cover the side slopes (T.D. No. 12), and (c) use of a single system to simultaneously collect both leachate and the gas from landfills (T.D. No. 4).

One general design innovation which can perhaps revolutionize the entire approach to the disposal of municipal and/or industrial waste would view landfills not as waste containment cells and repositories of indefinite and uncertain life requiring long-term care, but as reaction vessels and energy recovery centers with a definite service life (T.D. No. 10). Active degradation of waste and gas generation would be intentionally promoted and the operation would be aimed at achieving these objectives. The ability to predict service life would enable design for an estimated life and this would eliminate current uncertainties as to the long-term performance of the system components (e.g., LCS and liner) and the transfer of potential problems to future generations.

4.6.3 Miscellaneous Studies

Included in the category presented below are not only some miscellaneous LCS-related R & D needs but also some R & D areas which relate to the general topics of leachate management and characteristics and landfill design, including its components.

- Evaluation of various approaches to retrofitting older sites with LCS (T.D. No. 11).
- Better characterization of the type of wastes which are now sent to disposal sites and the expected future trends and their impacts on leachate characteristics (T.D. No. 15).
- Development of detailed specifications and guidelines on waste disposal site design and operation (T.D. No. 13); such

specifications should not provide strict standards, but rather guidelines for engineers to follow in examining options for developing solutions to site- and situation-specific conditions.

- Dissemination of the experience from full-scale facilities (T.D. No. 11).
- Development of background information and assessment of leachate problems associated with existing municipal landfills (T.D. Nos. 10 and 11). In general the environmental problems for these sites (many of which have little or no engineering design and have received large amounts of hazardous wastes presumably from numerous small generators) may be far greater than those from properly designed, dedicated hazardous waste sites.
- Developing means for predicting leachate characteristics at the time of design (T.D. No. 11).
- Development of cost-effective methods for leachate disposal (T.D. No. 11).
- Evaluation of the attenuation capacity of clay liners for leachates generated in municipal landfills (T.D. No. 9).

SECTION 5

EMISSIONS AND GAS CONTROL PROBLEMS AT LANDFILLS AND SURFACE IMPOUNDMENTS

5.1 PROBLEM OVERVIEW

Based on the limited emissions monitoring data which are currently available and the consideration of the fundamental nature and mechanism of gas production in landfills, little or no gaseous emissions would be expected from a properly operated strictly HWLF after its closure. Emissions from such landfills should be primarily related to the operating activities during waste placement and/or to the loss of volatile constituents from the leachate when and if the leachate comes in contact with open air (e.g., in the leachate collection sumps, standpipes and cleanouts when such appurtenances are left uncapped). As long as readily biodegradable wastes are not admitted, decomposition gases such as methane, which are produced in municipal and co-disposal sites and which require migration and emission control, should not be encountered in strictly HWLFs. Even if some biodegradable wastes are accepted, the toxicity of some hazardous wastes and the harsh disposal environment of certain sites can prohibit substantial biological activity in the mixed waste. Strictly hazardous waste sites represent premium disposal space and it would be essentially a mistake to send degradable wastes to or to accept such wastes in strictly HWLFs.

Gas can be produced in a HWLF as a result of chemical reactions and volatilization. This mechanism, however, would not be an important one in a properly operated site where strict controls are exercised so that solvents and bulk volatile wastes are not admitted and reactive wastes are passified before disposal or isolated in the disposal environment.

At co-disposal sites where hazardous wastes are admitted along with municipal refuse and/or degradable industrial wastes, the decomposition gases can pick up volatile toxic constituents from the hazardous waste. Since there are perhaps no municipal landfills in the country which have not received volatile toxic wastes (at least from the many small volume hazardous waste generators) or wastes which yield volatile toxic substances upon decomposition, all municipal landfills may be considered co-disposal sites presenting a potential for the emission of hazardous constituents to the atmosphere. This assertion is consistent with the results of surveys of the incoming wastes at municipal landfills and by the limited landfill gas data which indicate the presence of a variety of chlorinated and/or aromatic hydrocarbons in the municipal landfill decomposition gas.

The above concept of landfill emissions (i.e., considering municipal and co-disposal sites capable of emitting hazardous substances) is the basis for the discussion in this report.

The recently published Surface Impoundment Assessment National Report (17) indicated more than 180,000 active SIs in the U.S. These SIs are used for storage, treatment and disposal of a range of industrial, municipal and agricultural wastes. Although the potential threat of the SIs containing hazardous wastes to ground waters and surface waters has been recognized and received increasing attention in recent years, up to now little effort has been directed toward developing quantitative assessment of volatile toxic emissions from SIs and defining control technology requirements. Much of the concern over SI emissions has involved odor complaints in connection with specific SIs and source control and proper siting (in case of new SIs) have been the common mitigation measures used. As will be discussed in Section 5.4.2, much of the current and recent effort related to SI emissions involve development of sampling and analytical protocols and verification of emissions models.

5.2 REGULATORY BACKGROUND

5.2.1 U.S. EPA Regulations

Except for a general requirement in Part 264.301(f) of RCRA that the owners and operators cover or otherwise manage landfills to control wind dispersal of particulate matter, air emissions from hazardous waste landfills and surface impoundments are not specifically addressed by RCRA. The proposed RCRA reauthorization bills currently under consideration in Congress, however, will require EPA to promulgate regulations for monitoring and control of air emissions from hazardous waste treatment, storage and disposal facilities (TSDFs) as needed.

In preparing for its anticipated regulatory mandate, EPA has taken steps to consolidate its various relevant programs and as of February, 1984, the Office of Air Quality Planning and Standards (OAQPS) has been given the responsibility to develop appropriate programs for monitoring and controlling air emissions from TSDFs. Based on past experience it may take approximately 24 to 30 months, from the time that RCRA is reauthorized, to promulgate appropriate regulations (18). Because of the heretofore lack of hard data on TSDF emissions and control technology requirements, the focus of the current OAQPS programs is to determine the types and quantities of compounds being emitted. Considerable emphasis is being placed on developing sampling protocols, sampling and emissions measurements at selective sites, and verifying predictive models (18).

5.2.2 State Regulations and Concerns

Regulatory agencies of several states were contacted in the present program to develop an assessment of the state concerns and regulatory programs relating to emissions from LFs and SIs. In general, a certain degree of uncertainty was expressed as to the extent of emissions problems associated with LFs and SIs and of the control technology requirements. Because of these uncertainties, some states have implemented or plan to implement certain monitoring programs to better define the problem. Emissions control programs and requirements for LFs are generally specified on a case-by-case basis through the permit process. In general, gas migration and emissions controls is not considered to be a problem at strictly hazardous waste sites (except for the emissions associated with the open disposal activities), primarily because of expected absence of biological activity at these sites. Contingency provisions for gas collection and treatment, however, have been required at certain sites in the event that gas monitoring indicates the presence of high levels of toxic emissions associated with the vent gas.

Because of the heretofore absence of regulatory mandate from RCRA, some states have relied on the provisions of the Clean Air Act to regulate emissions from landfills through the permitting process and to evaluate air emissions from uncontrolled hazardous waste sites for cleanup under the Superfund Program.

A brief review of state programs and concerns is presented below, based on discussions with the representatives of the states of California, Michigan, Wisconsin, New Jersey and New York.

State of California (19)--

Since the discovery that vinyl chloride concentration levels in residential areas surrounding two LFs in Southern California exceeded air quality standards, the state has been very concerned with potential emission of toxic substances from LFs and SIs. The state Air Resources Board (ARB) is currently working with the State Department of Health Services (DHS) to develop air monitoring programs that will be incorporated into RCRA permits for HWLFs and SIs. Some form of periodic sampling around sites would most likely be required to determine impact of emissions on local air quality. Because air monitoring is very expensive, the state is currently seeking lower cost, less labor-intensive methods for measuring site emissions. Currently, gas migration control systems are specified on a case-by-case basis; individual

Air Quality Management Districts (AQMDs) are proposing their own requirements for methane, odor, and toxics control at landfills.

State of Michigan (14)--

Because the current RCRA regulations largely ignore air emissions from LFs and SIs, the state has relied on the Clean Air Act for authority in regulating these facilities. Under Michigan's Hazardous Waste Management Act, new and existing facilities must perform an environmental assessment before a permit can be issued. The assessment should include an estimate of the potential air emissions for the site. In the review process, the estimates of criteria pollutant emissions are compared with the National Ambient Air Quality Standards and noncriteria pollutant emissions (e.g., metals) are compared with standards developed by state.

Air monitoring requirements (e.g., sampling for acid fumes, metals, VOCs etc.) are set on a case-by case basis. However, all landfill owners must provide upwind and downwind sampling of total suspended particulates. No liquids of any kind are allowed to be disposed of in LFs as bulk liquids are considered to be a major source of VOC emissions and a potential for ground water contamination. The state also does not allow the impoundment of any volatile wastes in ponds and this is considered the best method of air emissions control for SIs.

State of Wisconsin (T.D. No. 9)--

Emissions from LFs and SIs have not been an issue in Wisconsin, as most sites are located in isolated areas. At one or two bigger sites, the state has required emissions monitoring, mainly for particulates. Passive gas management (venting) is required at all LFs, with the additional requirement that the system can be readily converted to active system, if necessary.

State of New Jersey *

The potential emissions from LFs and SIs are of recent concern in New Jersey, and the state is now in a learning process as far as regulatory requirements are concerned. The current state implementation plan calls for an emission rate of less than 7 lb/hr volatile organic substances for both active and closed LFs (this will soon be reduced to 3.5 lb/hr). Eleven organics, eight of which are chlorinated compounds, have been designated as

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* This section concerning the State of New Jersey has been reviewed by and incorporates comments received from Mr. William O'Sullivan, Chief, Engineering & Technology, Div. of Environmental Quality, New Jersey Department of Environmental Protection.

toxic and their emissions cannot exceed 0.1 lb/hr unless state-of-the-art air pollution controls are used. (The list of these toxic compounds, known as "Subchapter 17" compounds, will also be expanded to include non-chlorinated organic substances such as arsenic as well as other chlorinated compounds.)

There are also few (if any) municipal landfills in New Jersey (or perhaps anywhere else) which have not received hazardous wastes in the past. For the purpose of developing emissions monitoring programs, at the present time the state plans to rely on emissions monitoring results to establish control requirements on a case-by-case basis. (Based on landfill gas composition data which have been reported in the literature, toxic volatile organic substances can account for up to 1% of the raw gas collected from certain municipal sites).

The gas/emissions control activities in New Jersey are closely tied into and coordinated with the water pollution control and Superfund programs. It is believed that the removal of volatiles from a landfill through the use of gas collection/venting/control system should also reduce the level of such chemicals in the leachate, in addition to the prime benefit of providing for odor control by reducing air emissions.

About one year ago the state required vent systems for landfills (or landfill cells) which are closed. If the emissions monitoring indicates release of significant quantities of volatile organics, control of vents is required. It is estimated that about two years of emissions sampling may be required to develop the data base needed for problem definition. Landfill vent gases have been successfully burned in industrial process equipment and diesel engines. Two landfills are now installing gas collection and venting/flare systems.

The following is a preliminary draft of criteria which may be used by the state to judge the acceptability of an air pollution control permit application for venting landfills. The criteria apply to both hazardous waste and sanitary LFs, with the exception that the cost-benefit criteria will be $10 (1982 dollars) per pound of air contaminant prevented from being emitted into the atmosphere from a hazardous waste landfill emitting suspect volatile organic carcinogens:

- No odors off property line; and
- Less than 3.5 lb/hr volatile organic substance emissions or air pollution control at least 85% efficient; and
- Less than 0.1 lb/hr of each toxic volatile organic substance (TVOS) emitted or air pollution control designed for 99% efficiency with no less than 95% actual efficiency.; and
- Cancer risk less than 1 in a million, calculated with the

EPA Cancer Assessment Group risk factors and maximum annual ground level concentration off the property line, for a 70-year period; and
-Any additional reductions in air contaminant emission which would be cost effective, generally ranging from $1 to $10 (1982 dollars) per pound of air contaminant prevented from being emitted, depending on the substance.

The proposed New Jersey hazardous waste land disposal regulations will require a gas monitoring system, a gas monitoring program and gas venting ....if gas is detected outside the LF boundary, the state must be immediately notified and an abatement program must be submitted within 30 days of detection....... detected outside by sense of smell in any area of human use or occupancy."

Based on the state's experience with sanitary landfills, and depending on gas characteristics, the state may approve one of the following combustion technologies (all of which are proven control methods) for eliminating emissions of toxic vapors from landfills:

-"Enclosed" flare system such as that developed by Surlight Co.
-Venting to an industrial process furnace
-Venting to a diesel engine (catalytic converter requirement is being considered)
-Gas cleaning (upgrading) to pipeline quality (This technology may not be applicable to strictly HWLFs)

The state experience with carbon adsorption system for gas control has been very poor due to maintenance problems and the difficulty in estimating when the carbon bed needs changing or reactivation. Accordingly, this particular control is not recommended by the state. Table 7 presents the proposed New Jersey contaminant listing requirements for direct atmospheric venting or combustion control of LF emissions. These requirements are tentative and will change per results from ongoing and planned landfill monitoring programs.

At the present time, the state does not require any types of controls for HW SIs.

State of New York (20, T.D. No. 12)

Based on the limited avaialbale data, the state feels that it is very difficult to ascertain whether toxic vapor emissions from RCRA-designed LFs and SIs are indeed a real problem (or merely a public concern). The state plans to conduct emissions source testing at HW LFs and SIs to develop quantitative estimates of emission rates. State personnel have monitored for

TABLE 7. STATE OF NEW JERSEY CONTAMINANT LISTING REQUIREMENTS FOR DIRECT ATMOSPHERIC VENTING AND COMBUSTION OF LANDFILL GAS

A. Direct Venting to Atmosphere (no pollution control device)

- Total organics as equivalent methane
- Methane
- Any non-methane organics of a concentration of 1 ppmv or greater
- All Subchapter 17 compounds and vinyl chloride monomer
- Hydrogen sulfide and any other odorous compounds
- Carbon monoxide
- Carbon dioxide
- Moisture
- Heat value in Btu/standard cubic foot
- Total volume flow rate of gases
- Temperature of gases

B. In-situ or Off-site Combustion Control

Prior to Combustion:

- Total organics as equivalent methane
- All Subchapter 17 compounds and vinyl chloride monomer
- Total chlorine
- Total sulfur
- Carbon monoxide
- Carbon dioxide
- Oxygen
- Moisture
- Heat value in Btu/standard cubic foot
- Total volume flow rate of gases
- Temperature of gases
- Any non-methane organic with a concentration of 100 ppm or greater.

After Combustion:

- Particulates
- Sulfur Oxides
- Hydrochloric Acid
- Carbon monoxide
- Nitrogen oxides
- Total organics as equivalent methane
- Any non-methane organics that are greater than 100 ppmv in the inlet gas

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two years (through ambient air sampling) emissions from the two large commercial HW disposal sites in the state (i.e., the CECOS and the SCA facilities). One 24-hour sample is taken per month and analyzed using GC-MS techniques. During this period, only once have volatile organics been detected; concentrations of methyl ethyl ketone and carbon tetrachloride were in the low ppm to ppb range. However, particulates have been measured in much larger concentrations. Because of the multiplicity of emission sources at or in the vicinity of a complex facility such as SCA, it would be very difficult to assess the contribution from a specific source category (e.g., a specific LF or SI).

The LFs at CECOS and SCA facilities have gas vents which are capped and no pressure build-up has been noted. Since the leachate collection sumps are open to the atmosphere, there is a potential for emission of some volatile organic constituents present in the leachate, which may pass into the air space above the leachate surface. Measurement of the actual emissions from these sources has been heretofore hampered by a lack of reliable sampling protocols.

The state monitors the emissions from disposal operations at the two commercial hazardous waste sites using state-employed "on-site monitors". These monitors are graduate chemists that observe and approve of all disposal operations at the sites and report weekly to the state Air and Hazardous Waste Departments. The Air Programs Department relies heavily on these monitors in regulating these facilities. The state has requested that the monitors be given access to the operators' "selective adsorption tubes" (used per OSHA requirements in the work place) to assure that TLVs are not violated during disposal activities.

5.3 THE AVAILABLE DATA BASE ON LANDFILL EMISSIONS

Gases are generated by the decomposition or volatilization of many types of wastes disposed in landfills. When the gas generation rate is sufficiently high to produce an internal pressure within a landfill, convective gas transport can occur. When only small amounts of gases are internally generated, migration occurs primarily by diffusion. In either case gas movement is primarily in the direction of least resistance to flow, which can be laterally into surrounding strata or vertically into and through the cover material. While it is common to draw a distinction between municipal and hazardous waste landfills based on the types of wastes disposed, it should be remembered that some amounts of potentially volatile hazardous wastes are sent to municipal sites. Thus there is always a potential for a toxic emissions at any landfill. The difference between municipal and hazardous landfills is the potential quantity of gas generated rather than and the presence or absence of toxic substances in the gas. Considerable experience has accumulated in dealing with gases from municipal and co-disposal landfills and the discussion which follows focuses first on decomposition gas generation and its control at municipal sites.

5.3.1 GAS GENERATION AND MIGRATION AT MUNICIPAL LANDFILLS

Gas evolution within a landfill is a process of gradual volatilization and degradation of waste components via chemical reactions or microbiological processes. Landfill gases are produced slowly for months or years until waste constituents approach physical and chemical equilibrium and/or biodegradable materials have been exhausted (21-23). Municipal landfill gases are composed primarily of methane and carbon dioxide generated by biodegradation of carbonaceous wastes, but also contain hydrogen, ammonia, hydrogen sulfide, and aliphatic, aromatic and chlorinated organics. Landfill gas is usually odorous and can present explosion hazards if it concentrates in confined spaces.

The rate and quantity of gases generated are site-specific and depend on the moisture content of the waste medium, the amount and type of organics present, depth of the landfill, local climate, and acidity or alkalinity of the waste media (21). The pressure from internal gas generation is exerted in all directions and the gas will migrate through the most porous or fractured medium around the confined waste. Ultimately, most of the gas will diffuse to the atmosphere through the cover (or engineered vent systems) since lateral movement of landfill gas is restricted by static pressure within the fill and by the permeability of the surrounding liner or strata. Covers on landfills are perhaps the most difficult to seal, due to the effects of settling, freezing and thawing and burrowing animals (5). However , lateral migration can occur when very tight covers are established and/or the surrounding formation is highly porous and confining liners have not been properly engineered.

Emissions at the surface of or around a LF has historically been perceived primarily as a nuisance odor problem or as an explosion hazard (21, 23). In recent years it has also been recognized that LF gases contain reactive organics which can contribute to photochemical oxidant levels in ambient air (21, 23, 24). The presence of chlorinated and aromatic hydrocarbons in LF gases has been confirmed at a number of sites (25, 26).

In response to methane hazards and odor complaints, a number of operating or closed municipal landfills have been retrofitted with gas migration control systems, and most new sites have been required to provide such systems (e.g., see T.D. No. 9). Control systems may be either passive or active, but in either case they provide a porous conduit for gases to migrate to the surface for venting, incineration or energy recovery. It is now widely recognized that gas will form to some extent at landfills which have received carbonaceous wastes and that such gas will eventually migrate to the atmosphere. Designs and operating practices have evolved to provide for migration and disposal of gas.

Fugitive gaseous and particulate emissions also occur at all municipal landfills as a result of daily operations. Exposure of minimum waste area and application of daily cover serve to minimize emissions of odorous substances. Fugitive particulate emissions resulting from equipment use at the site, are perhaps more difficult to control, although often the particulate is primarily soil dust rather than waste components (23).

5.3.2 GAS PRODUCTION AND MIGRATION AT HAZARDOUS WASTE LANDFILLS

The nature of gas generation and movement at landfills which receive primarily or exclusively industrial hazardous wastes is different from that associated with municipal landfills. Although the types and characteristics of hazardous wastes can vary enormously, in most cases the wastes are not readily biodegradable and generation of methane and carbon dioxide is minimal. Although the trend is toward not accepting wastes which contain large amounts of potentially volatile substances, some wastes will contain small amounts of substances which can volatilize within the void space of the landfill medium.

The rate of waste volatilization in a landfill is highly dependent upon the physical and chemical properties of the waste and of the surrounding environment. Three related processes are involved in the volatilization of organic wastes: 1) volatilization of organic chemicals or mixtures of chemicals in liquid form, 2) volatilization of organics from water, and 3) volatilization of organic liquids absorbed by or adsorbed on waste solids or soils (27). Volatilization is driven by the equilibrium vapor pressure of individual substances in contact with the liquid or solid media and by the diffusion rate away from the waste source, which is in turn largely determined by the permeability of the waste medium and surrounding barriers.

Escape of volatile substances from the HWLF environment can be vertically through the cover material, laterally through porous formations or breaks in engineered barriers, and through engineered gas vent systems and leachate control plumbing. In the latter case, offgassing of collected leachate itself may be an important concern (28, T.D. No. 12). Unlike the situation with municipal landfills, however, it is in principle possible to engineer a nearly gas-tight hazardous fill since there is little internally generated gas pressure to promote migration.

Most natural soil and organic materials have the capacity for sorption of volatile organic substances (27, 29, 30). Thus the intermediate and final cover used at a HWLF can serve as a buffer to reduce volatilization of waste components. There is also evidence that many organics which are otherwise not readily biodegradable in concentrated form can, under proper conditions, be degraded by microorganisms when absorbed/adsorbed on surfaces of soil and/or organic particles. Of course such materials have a finite capacity and can be overloaded if large amounts of volatiles are generated within the fill.

5.3.3 Results from Actual Field Monitoring Programs

A number of landfill source testing and ambient monitoring programs have been carried out in recent years. For discussion purposes, these programs can be grouped into two categories. The first category of studies, which is reviewed in Table 8, has been of the general survey nature and has involved multiple site testing. The second category of studies, described in Table 9, has involved testing at specific sites and is largely in response to local complaints about odors and public health concerns.

As noted in Tables 8 and 9, the very limited number of recent attempts at systematic evaluation of emissions from HWLFs have been largely of a problem definition nature with a major objective of developing suitable sampling and analytical protocols. These preliminary and exploratory studies have yielded variable results (e.g., large data scatter) which have been attributed to emissions contributions from other sources and activities at the disposal sites tested and the yet unproven reliability and accuracy of the sampling and analysis protocols used (e.g., as indicated by the disagreements between results using different measurement techniques). Moreover, the representativeness of the sites has not been established. Given these limitations, the data from the limited source testing and ambient monitoring efforts indicate that even though closed hazardous waste landfills may emit some volatile organics, the measured or calculated ambient concentration levels of specific compounds (which can well include contributions from other activities at or outside the facility) are very low (usually near or below the detection limits of the methods employed) and nearly always less than the permissible OSHA exposure levels.

Considerable monitoring efforts have been conducted at and near the BKK Landfill in West Covina, California (see Table 9). The landfill is a co-disposal site and accepts a significant volume of hazardous wastes. Although over 40 organic compounds have been identified, including benzene, chloroform and vinyl chloride, the measured ambient concentration of these compounds has not exceeded the OSHA TLVs by more than a few percent. Hydrogen sulfide was identified as the primary source of odor. The working face of the landfill and the landfill gas flare system were identified as major emission sources.

TABLE 8. KEY SURVEY PROGRAMS RELATING TO TOXIC EMISSIONS FROM LANDFILLS

Program	Sponsor	Objectives	Description, Findings, and Significance
Air Pollution Sampling and Monitoring at Hazardous Waste Facilities. (31)	EPA/MERL-Ci	Collect data on ambient air quality near hazardous waste treatment and disposal facilities and conduct preliminary health risk assessment	15 HW sites, 8 of which involved landfill operations, were monitored for selected aliphatic and aromatic hydrocarbons in gas samples and trace metals in particulate samples. Samples were collected upwind and downwind of these sites, with an attempt to separately monitor different activities at the sites. Although increases in levels of Cu, Pb, Fe and Ni in particulates were found in downwind samples at some HWLFs, the trace element data show considerable scatter. For the measured organics, downwind levels were consistently higher than upwind levels. Comparison of downwind organic and trace element levels with OSHA workplace exposure levels indicated that none of the measured species was more than 2% of the respective OSHA permissible exposure limit. Chlorinated organics were identified in some gas samples, but the collection technique employed was not efficient for low molecular weight chlorinated hydrocarbons; thus quantitative results were not reliable. The representativeness of the data for the 8 HWLFs are not known, since the basis for site selection appeared to be largely operator cooperation.
Evaluation of Air Emissions from HW treatment storage & disposal facilities in support of RCRA air emission regulatory impact analysis--Sites 2 and 5 (28)	EPA/IERL-Ci	Develop and verify techniques for determining air emissions from HW facilities.	As part of a larger monitoring/methods verification program for emissions from HW facilities, two active and one inactive HWLF were monitored for a wide range of organics. Two monitoring approaches were employed for the active LFs: Transect (downwind array of monitors) and isolation flux chamber (IFC) (air inside confined space over a source is slowly displaced and the exit air monitored). At one active site, the transect technique gave highly variable results and transect emissions rates were very much higher than rates from the IFC technique. At the other active site, much better agreement was observed between the two techniques. Absolute emissions levels were greatly different at the two sites, presumably due to differences in the types of wastes disposed. At the inactive landfill, both IFC and gas vent monitoring were conducted. Emissions by the IFC technique at the LF surface and by direct vents sampling were intermittent and were not greatly above background when they did occur.

(Continued)

TABLE 8. (Continued)

Program	Sponsor	Objectives	Description, Findings, and Significance
			The study results are inconclusive. Apparently, emissions of toxic organics were measurable from active HWLFs but the best monitoring approach for quantifying emissions was not established. Also, the basis for selection of the monitored HWLFs is not known; consequently the representativeness of the study results cannot be assessed.
Landfill methane recovery Part II: Gas characterization (25)	Gas Research Institute	Develop standardized LF gas sampling/analytical procedures and a data base for volatile organic compounds (VOCs) in raw and processed LF gases.	9 MLFs in different parts of the U.S. were monitored for VOCs in well gases and surface gas samples (from confined space indicators, CSIs). The sites were chosen to cover the range of LF gas processing which currently exists in the U.S. VOCs were found in raw and processed gas from all 9 LFs, although total VOC levels and especially chlorinated organics, decreased with increasing levels of gas upgrading. Samples from CSIs showed large VOC variability both within a LF and among LFs. No correlation was found between CSI VOC levels and LF location or design features. It is not known whether any of the 9 MLFs was indeed a codisposal facility. The results do indicate that chlorinated and aromatic hydrocarbons are likely to be present in decomposition gases from most LFs, regardless of type of wastes received.

TABLE 9. INDEPENDENT MONITORING PROGRAMS AT LFS RELATING TO TOXIC EMISSIONS

Site Name/Location	Sponsor	Objectives	Description, Findings, and Significance
BKK HWLF, West Covina, CA (26)	BKK	Identify sources and nature of odorous substances which have led to local complaints and recommend appropriate corrective measures.	In 1980, the HWLF owner contracted with the Univ. of So. California to conduct a monitoring program and a review of manifest data for completeness and accuracy. Ambient air and surface gas samples (confined space indicators--CSIs) were taken on and around the LF site. Over 40 organic compounds were quantified including benzene, chloroform, and vinyl chloride. No compounds were found at levels of more than a few percent of the OSHA TLVs, although vinyl chloride often exceeded the California ambient standard of 10 ppbv. Hydrogen sulfide was the primary odor-causing substance; benzene was the most commonly found organic in the samples. The working face and the LF gas flare (which were subsequently modified) were implicated as the major emission sources. Additional gas extraction wells, improved operating practices and stricter enforcement of manifest requirements were recommended for reducing odor problems.
(32, 33)	So. Coast Air Quality Management District (SCAQMD), California Air Resources Board (CARB)	Determine effectiveness of corrective actions taken by BKK; identify ambient levels of toxic organics, provide data base for public health risk.	During the summer of 1982, ambient monitoring indicated that levels of halogenated and aromatic hydrocarbons downwind of BKK were well below OSHA TLVs but periodic exceedences of the California ambient vinyl chloride standard were still occurring. A source test of the LF gas incinerator found that halogenated organics and benzene were destroyed with greater than 99.7% efficiency. No additional health risk was estimated for persons living within one mile of the site.
Palos Verdes HWLF, Rolling Hills Estates, CA (34)	CARB	Survey of ambient air quality at LFs in CA. Field test recently adopted monitoring procedures.	The PV LF is a co-disposal facility which was closed in 1981. Onsite monitoring in 1983 indicated emissions of toxic organics due to cracks in the LF surface, vaults associated with collection wells, leaks at flare stations, and the vacuum desorption exhaust of the LF gas recovery system. Although a number of halogenated and aromatic hydrocarbons were detected, the onsite benzene level of 100 ppbv was estimated to pose the greatest health risk (approximately 1 excess cancer in 200 persons exposed).

(Continued)

TABLE 9. (Continued)

Site Name/Location	Sponsor	Objectives	Description, Findings, and Significance
Puente Hills MLF, Los Angeles County (34, 35)	CARB	Same as above.	Puente Hills is a large, active MLF which accepts limited amounts of liquid nonhazardous waste. Although hazardous wastes were not knowingly accepted at the site, ambient air monitoring in 1983 indicated the presence of halogenated and aromatic hydrocarbons. A preliminary risk assessment indicated approximately 1 excess cancer in 50 persons exposed to the 400 ppbv of benzene which was measured. Waste sampling programs, conducted in 1982 and 1983 to identify any hazardous waste in the incoming waste, found only a few tenths of a percent unacceptable material in household/commercial wastes. From these programs, it is not clear whether the small routine amounts of hazardous waste are the source of toxic emissions or whether these emissions originate from previously disposed wastes (before stringent enforcement) or result from degradation of plastics and other nonhazardous wastes.
Operating Industries (OI) MLF, Monterey Park, CA (36, 37)	SCAQMD	Enforcement monitoring of ambient air quality regulations.	There has been a long-term odor problem at the OI MLF site and several enforcement actions have been taken to mitigate emissions of odorous/toxic substances. Vinyl chloride has periodically exceeded the California ambient 10 ppbv standard and the source of this compound is not known since the LF does not accept industrial hazardous wastes. An impermeable plastic cover was installed over a portion of the LF in 1982 to enhance gas recovery. Soon thereafter, lateral gas migration problems led to increased incidence of odor complaints which prompted a new round of monitoring activities and court actions.
Mountain View MLF, Mountain View, CA (38,39)	Pacific Gas & Electric & U.S. Dept.	Comprehensive gas characterization as part of an experimental LF gas recovery project.	The Mountain View LF was one of the first in the U.S. to have a LF gas recovery system. The raw LF gas had relatively high levels of aromatics (140 ppmv) and halogenated hydrocarbons (100 ppmv) despite the fact that the hazardous waste had not been knowingly accepted at the site. Ambient gas samples at the site also showed higher levels of chlorinated organics than did offsite samples. Gas upgraded to pipeline standard had much lower levels than raw gases, but offgases from the upgrading process contained some of the toxic organics in the raw gas.

(Continued)

TABLE 9. (Continued)

Site Name/Location	Sponsor	Objectives	Description, Findings, and Significance
Misc. HWLFs:			
Stockton, CA (40)	CARB	Monitoring for toxic emissions as part of permit requirements of survey programs.	Ambient and/or gas vent monitoring at several sites has indicated that little or no emissions are occurring at closed HWLFs. Most measurements for toxic organics are at or near analytical detection limits.
New York (20, T.D. No. 12)	NY DEC		
Model City, NY (41, T.D. No. 12)	.SCA Chemical Waste Services	Estimate potential emissions from leachate collection system (LCS) at a HWLF in support of operating permit.	The subject LF was required to demonstrate that toxic emissions from the LCS were below "de minimus" levels in order to avoid installation of controls. Emissions were estimated using actual leachate composition data and a vaporization model based on Henry's Law constants for the identified organics. (See T.D. No. 12 for estimated emission values.

The characteristics of the landfill gas have been of considerable interest to companies/organizations which actively pursue energy recovery from landfills (see, for example, Refs. 25 and 42 and T.D. No. 16). Much of this interest has been in connection with development of suitable gas cleaning and upgrading processes, including mitigation of the corrosion problem in such systems. To date, the most extensive study of landfill gas characteristics, the results of which have been made public, is that carried out by ESCOR, Inc. Under the sponsorship of the Gas Research Institute, GRI (see Table 8). This effort involved a survey of the characteristics of gases extracted from nine LFs which apparently were primarily municipal sites with perhaps one or two co-disposal sites. Table 10 presents a list of the representative organic compounds identified in landfill gas. Since, unless a landfill is equipped with an effective gas extraction system, the gas would be gradually and eventually emitted to the atmosphere, compounds such as those shown in Table 10 should be considered as components of the atmospheric VOC emissions from LFs. The study indicated large variations in the VOC content of the gas, both among landfills and within a landfill (see also T.D. No. 16).

Table 11 presents the reported data on the concentrations of several specific chlorinated organics and aromatics and levels of total oxygenated organics and alkanes in the gas samples taken from interior gas extraction wells at several so-called municipal landfills, two known co-disposal sites, and one site which reportedly handled primarily nonhazardous industrial/commercial wastes. The data in this table indicate that (a) chlorinated and/or aromatic hydrocarbons are present in all landfills, regardless of the conventional/regulatory classification of a landfill as co-disposal, municipal, sanitary, nonhazardous, etc. site; and (b) the levels of these substances, which include some very hazardous compounds such as benzene, are not necessarily higher in the co-disposal sites which have knowingly accepted hazardous wastes. These conclusions are consistent with the information in Table 8 which indicates no correlations between odor problem (or vinyl chloride emissions) and the classification of the landfill. The variations in the level of individual substances or classes of substances among landfills shown in Table 11 indicate that gas composition is very site-specific (See also T.D. No. 16 and the discussion in Section 5.3.4).

5.3.4 Results From Discussions with Experts

The professional perspectives of those with whom technical discussions were held on the subject of emissions and gas migration problems at landfills are contained in the technical discussion summary reports presented in Appendix A. These perspectives, which generally reflect first hand experience with landfill design and operation, are consistent with the analysis

TABLE 10. ORGANIC COMPOUNDS IDENTIFIED IN LANDFILL GAS (25)

Benzene
Butylcyclohexane
Chlorobenzene
Cycloheptane
Cyclohexyl-eicosane
Decahydroaphthalene
Decane
Dichloroethane
Dichloroethene
Dichloromethane
Dichlorofluoromethane
Diethylocyclohexane
Dimethylbenzene
Dimethylcyclohexane
Dimethylcyclopentane
Dimethylheptane
Dimethylhexane
Dimethylhexene
Dimethyl(methylpropyl)cyclohexane
Dimethylpentane
Ethylbenzene
Ethylbutanol
Ethylcyclohexane
Ethylmethylbutene
Ethylmethylcyclohexane
Ethylmethylcyclopentane
Ethylmethylheptane
Ethylpentene
Heptane
Heptanol
Hexadiene
Hexane
Hexene
Isopropylbenzene
Iso-octane
Iso-octanol
Methylbenzene
Methylcyclopentane
Methylene-butanediol
Methylheptane
Methylhexane
Methyl(methylethenyl)-cyclohexene
Methylpentane
Methylpentylhydroperoxide
Methylpropylpentanol
Methylnonene
Octahydromethylpentalene
Octane
Naphthalene
Pentane
Propylbenzene
Nonane
Nonyne
Tetrachloroethene
Tetrahydrodimethylfuran
Tetramethylbutane
Tetramethylcyclopentane
Tetramethylhexane
Tetramethylhexenen
Tetramethylpene
Trichloroethane
Trichloroethene
Trimethylcyclohexane
Trimethylcyclopentane

presented above in Sections 5.3.1, 5.3.2 and 5.3.3. There is a substantial agreement among experts on some very key issues (e.g., the nature and extent of problem at strictly hazardous waste sites versus municipal or co-disposal sites). Some of the key points of the technical discussions with experts are presented below, along with reference to specific discussion (T.D. No.), which should be consulted for detail.

RCRA-Designed Hazardous Waste Landfills--

- Gas generation and migration/emissions control should not be of much concern at strictly hazardous waste sites after closure (T.D. Nos. 11 through 15), provided that such sites

TABLE 11. LEVELS OF ORGANIC COMPOUNDS REPORTED IN SAMPLES OF LF GASES FROM INTERIOR EXTRACTION WELLS (ppmv)

Landfill Compound	Mt. View CA*(38)	9 MLFs (25)† Max	9 MLFs (25)† Mean	Ascon, CA‡(38)	Puente Hills, CA*(34)	Palos Verdes, CA§(34)	BKK, CA§ (33)	Misc. LFs, CA¶(42) Max	Misc. LFs, CA¶(42) Min	Misc. LFs, CA¶(42) Mean
CHLORINATED ORGANICS										
1,2-Dichloroethylene	1.3	3.6	0.7	-	0.1	0.1	190	-	-	-
1,1-Dichloroethylene	-	1.1	0.1	-	2.4	6.2	70	-	-	-
Trichloroethene	1.9	7.6	0.7	-	60	6	265	-	-	-
Dichloromethane	-	5.6	0.7	-	-	-	-	-	-	-
Tetrachloroethene	0.6	8.3	0.8	-	70	7	430	-	-	-
Chloroethene**	-	-	-	-	24	7	600	-	-	-
1,1-Dichloroethane	-	5.2	0.32	-	-	-	-	-	-	-
Chlorobenzenes	0.9	11	0.41	4.1	-	-	-	-	-	-
Total Chlorinated	110††	396	12.7	-	-	-	-	1500	10	20
AROMATICS										
Benzene	-	23	1.6	5.5	50	200	200	112	2.7	32
Toluene	1.1	100	7	20.4	350	400	-	533	32	221
Xylene	0.5	115	4.6	14.9	350	600	-	765	24	220
Naphthalene	-	0.1	0.01	-	-	-	-	-	-	-
Total Aromatics	140††	311	30	80	-	-	-	1500	60	500
TOTAL OXYGENATED ORGANICS	175††	-	-	60	-	-	-	-	-	-
TOTAL ALKANES	3400	94	7	114	-	-	-	-	-	-

*Municipal landfills

†Although not identified, there are indications that one or two co-disposal sites may have been included in the sites surveyed

‡Site handled primarily nonhazardous industrial wastes

¶Number, location or classification of sites not identified

§Co-disposal site

**Vinyl chloride

††Compound class data (i.e., "totals") are for a sample other than that used for individual compound analysis

were designed, operated and closed per RCRA requirements. Source control, which disallows accepting bulk wastes which are readily decomposable or reactive or contain volatile substances, and the toxicity of the waste environment should suppress biological activity (which results in the formation of decomposition gases) and waste volatilization. Even if some waste volatilization and degradation occurs, the internal gas pressure would not be very high to effect gas migration via convective mechanism; a properly designed and maintained soil cover will have sufficient adsorptive capacity to prevent significant emissions (T.D. Nos. 1, 4 and 15). Gas venting systems which have been provided at some closed hazardous waste landfill cells have been primarily as a precautionary measure (T.D. Nos. 12, 13, 14) and no pressure buildup has been noted based on monitoring of gas pressure in the capped vents (T.D. No. 13).

- Little actual emissions and ambient monitoring data are available to quantify the extent of emissions (if any) from HWLFs. Some state requirements for monitoring at certain sites and for provisions for gas control should a problem develop (T.D. Nos. 12 and 14) primarily reflect the uncertainty as to the nature and extent of emissions and stem from public concern rather than hard data indicating emissions of hazardous constituents (T.D. No. 14).

- Ambient and source testing for landfill emissions is currently in an evolutionary stage and no reliable protocols have yet been developed (T.D. Nos. 10 and 12). The problem is complicated due to multiplicity of emissions sources at or around major sites which makes it very difficult to interpret ambient air monitoring results (T.D. No. 12).

- At a properly operated landfill site, emissions from pretreatment and waste processing activities, which preceed the actual disposal, would be of greater significance than emissions from waste placement and/or landfill after it is closed (T.D. Nos. 4 and 15). In this regard, hazards to landfill personnel and maintenance crews are of greater concern than emissions from closed LFs (T.D. No. 15).

- Leachate collection sumps, standpipes and accesses can conceivably be a source of atmospheric emissions at closed hazardous waste landfills. Very limited testing data which have been developed have been inconclusive due to lack of appropriate testing protocols (T.D. No. 12) or have indicated no emissions of consequence (T.D. No. 14). Leachate collection sumps and cleanout accesses are generally kept closed; they can, at most, represent only a potential source of intermittent emissions when they are opened for maintenance purposes (T.D. No. 15).

- The potential for emissions from closed hazardous waste landfills would even be less in the future due to increasing emphasis on source control and waste treatment and passification prior to disposal (T.D. No. 15).

Municipal and Co-disposal Sites--

- Gas generation and migration are problems which are primarily associated with co-disposal and municipal landfills where the waste undergoes decomposition (T.D. Nos. 9, 14, 15 and 16). The migrating gas can contain traces of toxic substances and hence present emission problems. These toxic substances can originate from wastes containing toxic volatiles and/or result from degradation of otherwise inert wastes (e.g., vinyl chloride produced from the degradation of plastics) (T.D. No. 15).

- The quantity (e.g., yield) and characteristics of landfill gas are highly variable and extremely site-specific and these variations are not necessarily related to any regulatory or conventional classification of sites as co-disposal, municipal, sanitary, etc. (T.D. No. 16).

- Gas monitoring data have indicated no substantial differences in the gross composition of the gas from the co-disposal and the so-called municipal landfills (T.D. Nos. 4 and 15). Thus compounds such as xylene, toluene and benzene which have been identified as trace hazardous constituents in the gas from co-disposal sites, have also been identified in the gas from municipal landfills (T.D. No. 15). This compositional similarity is not surprising since all municipal landfills receive various quantities of hazardous wastes (e.g., from small volume hazardous waste generators). Thus the differences in the composition of gas from municipal and co-disposal sites and hence the emission problems appear to be a matter of degree rather than kind (T.D. No. 15). Gas and emission control systems for the two landfill types would also be the same in fundamentals but vary in complexity and details (T.D. No. 15).

- Unless the gas from municipal and co-disposal landfills is recovered, in addition to safety hazards associated with off-site gas migration, landfill gas can constitute a major source of air pollution (T.D. No. 16). Since landfill covers only postpone gas emission (i.e., after steady-state conditions are reached, soil covers are ineffective in preventing gas escape), landfills can emit very large quantities of reactive organics and substantial amounts of potentially hazardous substances which are present in landfill gas as trace constituents.

- The nature and extent of emissions at municipal and co-disposal sites are largely a function of the extent of waste screening and processing to eliminate or passify problem wastes, waste placement practices and the control systems employed (T.D. Nos. 1 through 4, 9, 10 and 12 through 16). No significant emissions would be expected from landfills which employ an active gas control systems which is very large in extent and which maintains a vacuum in the collection system (T.D. No. 1). Actual ambient monitoring data around some such landfills have indicated no substantial differences between upwind and downwind conditions (T.D. Nos. 1 and 15). Passive control systems employing direct atmospheric venting do not eliminate the emissions problem since any toxic substances in the gas would still be released to the atmosphere (T.D. No. 15). The state of Wisconsin requires passive gas management at all sites, with the additional requirement that the system can be readily converted to active system if necessary (T.D. No. 9). When the vent gases are flared, little or no emissions of reactive organics are expected due to high temperature of the flare (1400-1500°F) (T.D. Nos. 1 and 4). At sites in California where flaring has been employed, the flare emissions have met the very restrictive local air quality standards (T.D. Nos. 1 and 4).

- At least in the dry climates such as in Southern California, underground fires in the landfills are a rule rather than an exception (T.D. No. 4). The heat from such fires can increase volatilization and hence the potential for emissions of hazardous air pollutants (T.D. No. 4). Underground fires have not been a problem in Wisconsin due to the wet climate and strict regulation and inspection which would prevent disposal of hot ashes and flammable wastes in landfills (T.D. No. 9).

- Installation of covers for landfills to minimize infiltration, increases the potential for gas migration and hence necessitates gas venting (T.D. No. 11). Properly designed soil covers can reduce emissions of some hazardous substances through adsorption and/or biological degradation (T.D. No. 4). Odor measurements have indicated several orders of magnitude reductions in the odor as the gas passes through the cover (T.D. No. 1). The odor reduction is believed to be due to aerobic biological activity within the cover (T.D. No. 1) which has been shown to occur in the bottom layer of the soil cover (T.D. Nos. 1 and 4).

- Few odor and gas complaints are received on many landfills, since they are located in remote areas (T.D. Nos. 5 and 9).

- Gas generation in landfills should not be viewed as a problem area to be contended with, but as an opportunity to recover a valuable resource (T.D. No. 10). Thus, landfill design and operation should be geared toward the goal of recovering maximum amount of gas requiring minimal pretreatment prior to use. In addition to source control, whereby wastes are screened and troublesome wastes are identified for proper handling (i.e., sent to strictly hazardous waste disposal sites, treated, or disposed of in segregated areas), operating procedures should promote active waste degradation (e.g., through leachate recyling and biological seeding) and eliminate internal barriers to gas movement (e.g., using permeable materials as intermediate cover). Use of horizontal trench gas recovery systems, which are constructed in the fill as the waste is placed, or shortly thereafter, enables recovery of a greater amount of energy (and better odor control) than the conventional vertical well gas extraction systems placed in a completed landfill (T.D. No. 1).

- To promote energy recovery from landfills and in line with the consideration that landfills can emit significant quantities of reactive and hazardous substances to atmosphere, from a regulatory standpoint landfills should be considered as point sources of emissions and gas recovery as the "Pollution control device" for landfills (T.D. No. 16).

5.4 THE AVAILABLE DATA BASE ON SURFACE IMPOUNDMENT EMISSIONS

5.4.1 Some Fundamental Considerations

Volatile chemicals in the wastewaters discharged to SIs can escape into the air and result in an area-source of emissions. The rate of escape of a volatile substance from a liquid surface may be expressed by the following equation (43):

$$(ERP)_i=(K_{OA})A(x_i-x_i^*)M_i \qquad \text{(a)}$$

where $(ERP)_i$=emission rate potential of a compound, g/sec;
K_{OA}=overall mass transfer coefficient, g-mol/cm2-sec;
A=SI surface area, cm2
x_i=concentration of the compound in the wastewater, mole fraction;
x_i^*=equilibrium concentration of the compound in liquid corresponding to its partial pressure in the gas phase, mole fraction; and
M_i=molecular weight of the compound, g/g mol.

Expressing the solute concentration as Ci in mg/l, the emission rate potential equation becomes:

$(ERP)_i=(18 \times 10^{-6})(K_{OA})A\ C_i$ (b)

The critical variable of the estimation depends upon the overall mass transfer coefficient K_{OA}. K_{OA} can be calculated from K_L, K_G, and K, using the well established "two resistance" theory as follows:

$1/K_{OA}=1/K_L+1/KK_G$ (c)

where K_L=liquid phase mass transfer coefficient, g-mol/cm2-sec;
K_G=gas phase mass transfer coefficient, g-mol/cm2-sec; and
K=equilibrium constant of liquid and gas phases, dimensionless.

The K value can be determined by the following equation:

$K=(H_i/PM) \times 10^6$ (d)

Where H_i=Henry's law constant of the compound, atm/(g-mol/m^3);
P=total pressure, atm; and
M=average molecular weight of the liquid, g/g-mol (the factor of 10^6 is derived from conversion of liquid weight into volume.)

Eq. (c) represents the addition of two phase resistances in series to yield an overall resistance. The relative contribution of each resistance can be calculated. Most of the resistance to volatilization lies in the few millimeters above or below the gas-liquid interface. In many situations either liquid phase resistance or gas phase resistance controls; but in some cases, both resistances control. If "K_L" is very small compared to "KK_G", the liquid phase resistance controls and "K_G" may be ignored, and vice versa. The distribution of resistance depends on K_L, K_G, and K which must be quantified. For H_i values above 10-3, the transfer is liquid phase controlled and the gas phase may be ignored for practical purposes, i.e., $K_{OA} = K_L$.

Based on the above theoretical considerations, the loss of volatiles from SIs would be highly variable and site- and situation-specific. The volatilization rate would depend on the degree of turbulence at the gas-liquid interface and would be greatly influenced by the presence of surface materials such as floating solids and/or liquid films. Because of the complicated effects of surface materials, turbulence and the meteorological conditions, which may vary appreciably with time, it is very difficult to quantify various film resistance coefficients (K_L, K_G and K) and develop reasonably accurate estimation of volatilization losses based on theoretical considerations. As will be discussed in Section 5.4.2, some of the mathematical models which have been developed for predicting emissions, based on theoretical considerations such as those presented above, have yielded emissions estimates which have differed from the results obtained via direct measurement. Since a predictive capability would be helpful to permit writers while the proposed impoundment is in planning and design stages, considerable emphasis is being placed on model verification and improvement.

5.4.2 Results from Previous Studies

Table 12 describes and presents the results from three recent SI emissions monitoring programs and one general study of atmospheric release of chlorinated organic compounds from the activated sludge process. This latter study, which is an example of a number of studies (e.g., Refs. 47 and 48) addressing the loss of volatile organic substances from wastewater during various treatment processes, has been included to illustrate the impact of wastewater characteristics (e.g., molecular weight of organics, presence of biological flocs, etc.) and the treatment processes themselves on the volatilization of organic substances. These studies have indicated that low molecular weight halogenated and aromatic hydrocarbons can be readily volatilized from SIs. In one study of an aerated lagoon (48), half lives calculated from emissions data were only a few hours. Data from open primary and secondary wastewater treatment systems also indicate very short half lives for the low molecular weight organics (45). Even less volatile organo-chlorine pesticides and pesticide metabolites are reportedly lost to a large extent to the atmosphere in highly aerated treatment systems.

As noted in Table 12, the SI monitoring studies have been mostly concerned with comparative testing of various sampling protocols and equipments and with verification of various models for predicting emissions. Since only a very limited number of SIs have been included in these studies, the results, which generally indicate very low VOC emissions (often near the detection limit for the sampling and analytical methods used), may or may not be representative of the emissions from SIs. Moreover, there have been some significant disagreements between the results using different sampling protocols such as emission isolation flux chamber (ICF) vs. concentration profile method (C-P) and between the measured values and those predicted using models. These discrepancies thus cast some serious doubt as to the validity of the current data base on SI emissions and underline the need for additional R & D to develop improved sampling methods and equipment and for field measurements at additional sites. The following excerpt from the Conclusions Section in the final report for the second study in Table 12 (Ref. 44) illustrates the discrepancies and variability in the data:

> VOC emissions were measured using a modification of the C-P technique at two chemical waste treatment facilities, one using an aerobic bio-oxidation pond

TABLE 12. KEY PROGRAMS RELATING TO TOXIC EMISSIONS FROM SURFACE IMPOUNDMENTS

Program	Sponsor	Objectives	Description, Findings, and Significance
Evaluation of air emissions from hazardous waste treatment, storage and disposal facilities in support of RCRA air emission regulation impact analysis--Sites 5 and 6 (28)	EPA/IERL-Ci	Develop and verify techniques for determining air emissions from SIs and to validate available emissions models.	As part of a larger, multi-site monitoring program at HW facilities, emissions were measured from a reducing lagoon, an oxidizing lagoon, a wastewater holding pond, and a spray evaporation pond. The first three types of SIs were monitored using the emission isolation flux chamber (IFC) and concentration profile (C-P) techniques. For most compounds, the IFC yielded higher rates than the C-P technique. Measurements by either technique were generally much lower for the two lagoons than that predicted by the models employed (which used liquid-phase concentration data). For the holding pond, predicted rates were greater than C-P values but less than IFC values for the spray evaporation pond. Emissions were measured by the transect technique, and the results were much lower than those projected by the model calculations. Considerable variability was found in both the gas and aqueous sample data which contributed to wide confidence intervals for both predicted and measured emissions rates. The lack of agreement between model and measured rates was attributed in part to effects of oils and solids in the SIs and, in the case of the spray pond, to atomization and evaporative cooling effects due to spray nozzles.
Evaluation of VOC emissions from wastewater systems (secondary emissions) (44)	EPA/IERL-Ci	Obtain data for evaluating carbon (VOC) emissions from wastewater treatment facilities for the synthetic organic chemicals manufacturing industry.	VOC emissions were measured using the C-P technique at oxidation pond and a non-aerated pond. Emissions at both ponds were near the detection limits for monitoring techniques employed (3 ppbv. Model predictions tended to overestimate measured emissions for most organics by factors of 3 or more for the aerated systems and 6 or more for the non-aerated systems. For at least two polar organics, measured emissions rates were less than those predicted by model calculations, which may be a consequence of low analytical data for the "purge and trap" sample collection technique for pond water organics.

(Continued)

TABLE 12. (Continued)

Program	Sponsor	Objectives	Description, Findings, and Significance
Air emissions monitoring of hazardous waste sites (45)	EPA/HERL Solid & Hazardous Waste Research Division	Identify volatile organics from SIs and compare results with model predictions.	Emissions of chlorinated and aromatic hydrocarbons were measured using the C-P technique at an oxidation pond which handled industrial wastewater. C-P emissions rates agreed with model calculations within a factor of 2. Half lives for volatilization of benzene and 1,1-dichloroethane from the SIs were around 3 hours for aerated SI and 7 hours for the holding pond. The transport process for volatilization of chemicals from the SIs was found to be liquid phase controlled.
Atmospheric release of chlorinated organic compounds from the activated sludge process (46)	EPA/U.S. Air Force	Identify locations in wastewater treatment process where emissions of chorinated organics occur.	Aqueous and gaseous samples were taken at various locations within an activated sludge plant to estimate stripping of low-and-high molecular weight chlorinated hydrocarbons at various stages of processing. The low molecular weight compounds were largely lost at early processing stages (e.g., at the grit chamber wier) while higher molecular weight organics were lost mostly at the contact aeration basins. Relatively nonvolatile compounds such as hexachlorocycloheptene appeared to be adsorbed onto the biomass which were recycled to aeration basins from clarifiers, prolonging their atmospheric release. The low molecular weight organics were 80-99% volatilized during the process, while high molecular weight organics were about 50% volatilized.

(site FB), and the second using a nonaerated pond (site TB). Emissions from both sites were very low, near the detection limits for the sampling and analytical methods which were used (3 ppbv-C). VOC flux rates were calculated for benzene, diethyl ether, indene, and styrene at site FB. Also, a flux rate was determined for the total aromatic content in the air above the pond surface. Measured flux rates at this site ranged from 430 kg/Ha-yr for styrene to 3660 kg/Ha-yr for diethyl ether. The average flux rate for total aromatics at this site was 20,400 kg/Ha-yr. VOC flux rates at site TB were determined for benzene, cyclohexane and acetone. Measured flux rates at this site ranged from 130 kg/Ha-yr for benzene to 1550 kg/Ha-yr for acetone. Standard errors and confidence limits were calculated for all analytical and meteorological measurements. Because of the low levels of VOC species which were present above the ponds and sampling and analytical variabilities, a zero flux rate was within the 95% confidence level for all flux measurements.

Flux rates determined using the modified C-P technique were compared to flux rates predicted by the models of Thibodeaux and Hwang. Results of the comparison were variable, and seemed to be related to the type of compound and whether or not aerators were used. For the site containing aerators (FB), predictive flux rates for the three aromatic compounds were approximately 3.5 times higher than measured flux rates. However, for diethyl ether, the predicted flux rate was only 35% of the measured flux rate. Predicted flux rates for diethyl ether and styrene were within the 95% confidence limits for the measured rates, while benzene and styrene were outside the 95% confidence limits. The predictive model indicated that 85-95% of the overall emissions resulted from aeration (turbulent phase).

For the site not containing aerators (TB), predictive flux rates for benzene and cyclohexane were greater than measured rates by factors of 10.0 and 5.9, respectively. The predicted flux rate for acetone at this site was 15% of the measured rate. The predicted flux rate for acetone was within the 95% confidence limits for the measured value, while predicted flux rates for benzene and cyclohexane were not.

As with LFs, a major problem with quantifying emissions from SIs has been that the SIs tested are often located at sites where there are other sources of emissions. At these sites it is very difficult to separate SI emissions from the background levels or from emissions caused by other on-site or nearby off-site activities (see also T.D. No. 12). The following conclusions from the third study listed in Table 12 illustrates the point:

> Levels of chlorinated hydrocarbons, including 1,1-dichlorethane, and total hydrocarbons, including benzene, were observed in both the water and air boundary layers of two SIs of a hazardous waste facility. Concentration gradients in the air boundary layer above the SI indicate that the ponds are a source of VOCs; however, periodic wind shifts move air with high concentration of VOC from other areas of the facility over the impoundments so that chemical absorption onto the water is indicated.

5.4.3 Results from Discussions with Experts

Perhaps because of their temporary nature and the greater flexibility in controlling their emissions, the problem of emissions from SIs have not been of major concern. The problem with potential odor has generally been addressed through siting and source control (i.e., not accepting odorous wastes or wastes which would react to produce malodorous compounds) (49) For example, in Maryland, the volatile wastes are shipped out of state for treatment and disposal (T.D. No. 5) and in Wisconsin and Maryland odor and emissions have not been a problem because TSDFs are located away from residential areas (T.D. Nos. 5 and 9). The state of New York has developed rules on the type of waste which can be admitted to a hazardous waste disposal site. At major commercial hazardous waste sites, the rules are strictly enforced by on-site state inspectors (T.D. No. 12). As with the hazardous waste landfills, because of the multiplicity of emissions sources at and the locations of some commercial sites it has been and would be difficult at these sites to separately measure the emissions contributions from individual SIs (T.D. No. 12). Chemical Securities System, which operates a major hazardous waste in Arlington, Oregon, has recently initiated a monitoring program to determine the nature and characteristics of emissions from some 18 SIs which are present at the site (50).

5.5 CORRECTIVE AND PREVENTIVE MEASURES

5.5.1 Landfills

RCRA-Designed Hazardous Waste Landfills--

As noted in Section 5.3, the very limited actual emissions and ambient monitoring data which are currently available for hazardous waste landfills and the consideration of the fundamental nature of gas generation and migration in landfills would suggest that gas migration and emission should not be of major concern at strictly hazardous waste sites which meet or exceed RCRA design, operation and closure standards. Since biological activity at these landfills is minimal, emission at a closed landfill primarily relates to waste volatilization and this can be addressed through source control and site design. Because of the uncertainty regarding the nature of emissions problems at strictly hazardous waste sites and a possible need for add-on controls, some such sites feature gas venting systems for the closed cells (T.D. Nos. 12, 13 and 14); the vent pipes are capped, but can be converted/connected to gas collection and treating system, if gas monitoring data point to such a need. Figure 6 presents detail of a gas venting system for a closed cell at a hazardous waste landfill.

Many of the measures for controlling gas emissions in hazardous waste landfills are preventive rather than corrective in nature. These measures, along with those for controlling fugitive emissions from waste handling and placement, have been grouped into design- and operation-related categories and are briefly described in Tables 13 and 14, respectively.

In reviewing control measures, it should be noted that such measures should be integrated with and are affected by leachate control methods (see Section 4.5). Thus a tight cover design which reduces infiltration and hence leachate generation can necessitate incorporation of vents in the cover design as a gas pressure release contingency measure. Similarly, source control measures for control of leachate volume and characteristics (e.g., not accepting bulk liquids and degradable wastes) also reduce the potential for generation of decomposition gases.

A number of studies have been conducted in recent years aimed at determining the factors which affect the rate of volatilization of toxic organics in a landfill environment so that better controls can be developed. These studies which have been largely laboratory-type and research-oriented are listed in Table 15. Three of the studies listed in the table measured volatilization rates for specific organics from real or synthetic wastes when the waste was covered by materials having different porosities and water contents. Compacted clays, soils, and organic materials were found not only to reduce the rate of volatilization, but also provide adsorption capacity for many organics. Higher water contents in clays serve to decrease porosity which in turn decreases volatilization rate from underlying waste.

There is some evidence that organic matter in the final cover of a landfill can, in addition to providing physical sorptive capacity for toxic substances, contribute to the eventual biodegradation of some of these substances. Organic matter added to cover soil can provide seed organisms which may

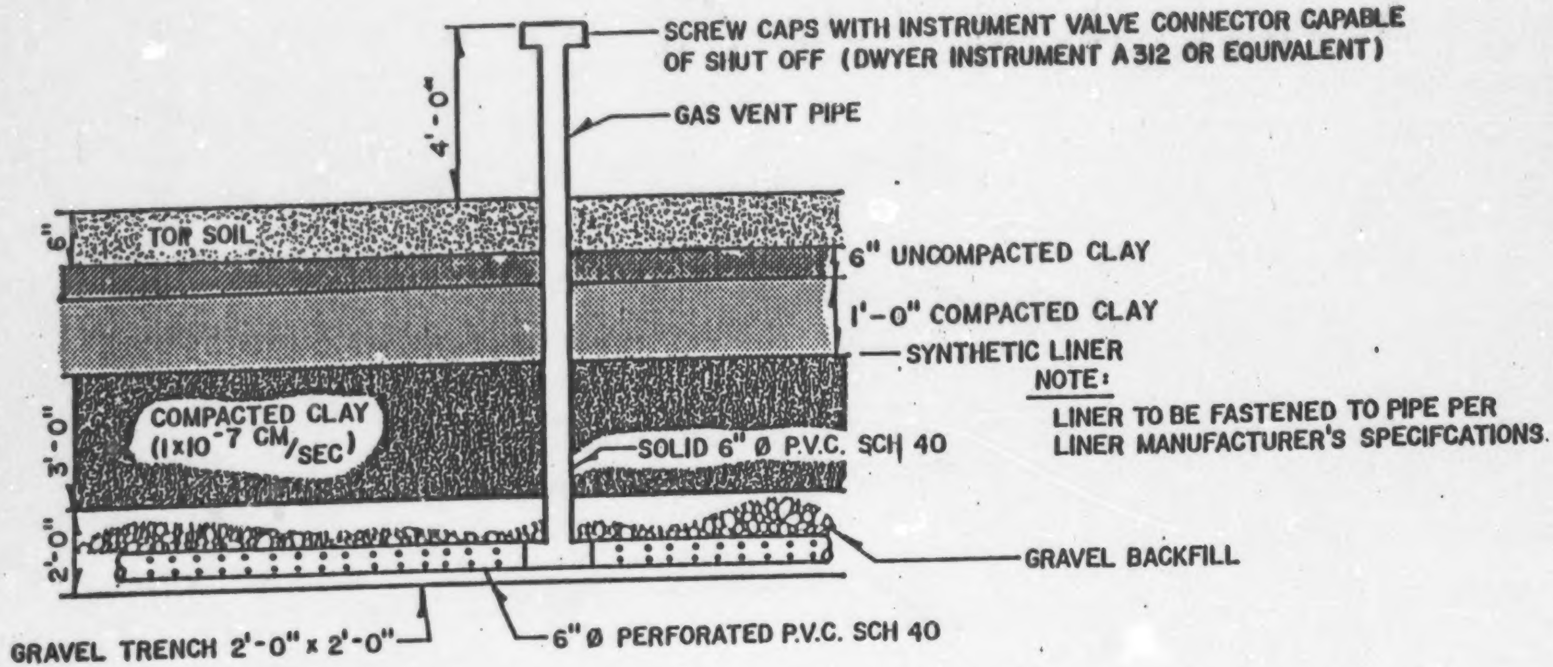
SCREW CAPS WITH INSTRUMENT VALVE CONNECTOR CAPABLE OF SHUT OFF (DWYER INSTRUMENT A312 OR EQUIVALENT)
GAS VENT PIPE
4'-0"
6"
TOP SOIL
6" UNCOMPACTED CLAY
1'-0" COMPACTED CLAY
SYNTHETIC LINER
NOTE:
LINER TO BE FASTENED TO PIPE PER LINER MANUFACTURER'S SPECIFCATIONS.
COMPACTED CLAY (1x10-7 CM/SEC)
3'-0"
SOLID 6" Ø P.V.C. SCH 40
2'-0"
GRAVEL BACKFILL
GRAVEL TRENCH 2'-0" x 2'-0"
6" Ø PERFORATED P.V.C. SCH 40

Figure 6. Gas venting detail for a closed cell at a hazardous waste landfill (T.D. No. 13)

TABLE 13. PREVENTIVE/CORRECTIVE DESIGN-RELATED MEASURES FOR GAS GENERATION AND MIGRATION/EMISSION CONTROL AT HAZARDOUS WASTE LANDFILLS

Measure	Description and Comment
Multiple cell design for segregated waste disposal	-Dedicating specific landfill cells/areas to specific waste categories would allow for tailoring design and operation to waste-specific properties thereby providing for more cost-effective gas migration and emissions control.
State-of-the-art liner and cover design	-Prevent lateral gas migration and allow for engineered gas venting through cover and possible collection and treatment of gas before release. -Reduce infiltration into the landfill thus reducing leaching and potential for biological activity.
Use of capped vents, sumps, cleanouts, etc.	-Prevent potential uncontrolled release of volatile toxic substances to atmosphere. -Allow for monitoring of pressure and composition of landfill gas or leachate off-gas.

TABLE 14. PREVENTIVE/CORRECTIVE OPERATION-RELATED MEASURES FOR GAS GENERATION AND MIGRATION CONTROL AT HAZARDOUS WASTE LANDFILLS

Measure	Description and Comment
Source control	-Not accepting solvents. -Not accepting or passifying (e.g. through solidification) liquid wastes, reactive wastes, wastes high in volatiles, readily biodegradable matters. -Surrounding specific waste loads with absorbents as a contingency measure.
Prevent formation of internal barriers to gas flow.	-Use of sand or other permeable material as intermediate cover. -Providing discontinuities in the intermediate cover or breaking previous day's cover in the active filling area.
Control of runoff and and infiltration (to suppress leachate formation and biological activity).	-Runoff diversion and containment and removal of rainwater entering active site. -Use of temporary domes and roofs during operation. -Proper cover maintenance after closure. -Removal of ponded water during active life.
Control of fugitive emissions due to waste handling and placement activities.	-Limiting the exposed working face of landfill. -Source control (see above). -Conducting waste processing in enclosed areas equipped with emission control. -Operating under low temperature and low wind speed (when possible) -Covering the waste immediately after disposal with suitable cover

TABLE 15. KEY LABORATORY/SUPPORT STUDIES RELATED TO VOLATILIZATION OF TOXIC ORGANICS FROM WASTES AND SORPTION/BIODEGRADATION IN SOILS

Study Title	Objectives	Description, Findings and Significance
Studies of Emissions and Control of Volatile Organics in HWLFs (51)	Determine factors controlling movement of volatile organics away from wastes in a simulated LF environment.	Using benzene as a model toxic waste component, the study investigated volatilization rates from simulated wastes covered with clay, soil, and organic matter. Cover material had varying capacities to sorb benzene. At steady state (cover saturation) the volatilization rate was directly related to cover porosity and inversely to cover moisture content.
Problems Associated with Land Disposal of Hazardous Waste Containing Hexochlorobenzene (HCB) (29)	Determine effects of various cover materials on HCB volatilization rate in simulated waste environment.	HCB containing waste was covered with soil, polyethylene film, water and the volatilization flux measured. Soil and water were both very effective in reducing steady state flux. The soil adsorption capacity retards the time required to reach steady state. Thin polyethylene film did not greatly affect volatilization.
Gas Chromatographic Studies of Sorptive Intersections of Normal & Halogenated Hydrocarbons with Water-Modified Soil, Silica, and Chromosorb W (52)	Quantify sorption properties of various materials for hydrocarbons under GC conditions.	Using soil, silica and Chromosorb W as GC column materials, the sorption of halogenated and normal hydrocarbons was investigated. Wet soil is highly effective in sorbing organics, with greater sorption constants exhibited for higher than for lower molecular weight organics.
Investigations of the cover of a closed HWLF as an odor suppressant (T.D. No. 1)	Determine the effectiveness of final cover in reducing odor emissions	L.A. County Sanitations Districts has made numerous odor measurements at its Palos Verdes Landfill and has determined several orders of magnitude reduction in odor as the gas passes through the cover. The reduction in odor has been attributed to biological activity within the the cover.

develop the ability to degrade toxic organics. Organic matter also provides a large surface area and nutrients for microbiological growth, and porosity for diffusion and movement of organic vapors, water vapor and metabolic wastes in the soil. In this regard sewage sludge, wood chips, mulch or compost, shredded newspaper, and similar materials may be beneficial as part of the final cover for landfills.

Municipal and Co-disposal Landfills--

Fugitive emissions of toxic substances at municipal and co-disposal sites can result from operating activities and from migration of decomposition gases containing toxic substances as trace contaminants. Source and operating controls, venting, interception and/or collection of gas for incineration with or without energy recovery constitute controls for gas migration and emissions problems at municipal and co-disposal sites. As with the controls for hazardous waste sites, some of these measures are primarily preventive rather than corrective.

Source controls at municipal and co-disposal sites are primarily aimed at (a) excluding disposal of bulk solvents and waste containing a high concentration of volatiles and/or (b) passification of certain troublesome wastes (e.g., via solidification) prior to disposal. To prevent lateral migration of gas to nearby structures, and to facilitate gas collection for energy recovery, operating controls are aimed at eliminating internal barriers to gas movement (e.g., through use of sand or other permeable materials as intermediate cover).

Various systems have been employed at a number of municipal and some co-disposal sites for interception and venting and for collection and disposal or use of landfill gas. These systems fall into two categories: passive and active systems. Key features of these systems are listed in Tables 16 and 17, respectively. The passive systems are aimed at releasing the internal gas pressure by providing wells and trenches in or around landfills for venting of the gas to the atmosphere. Passive systems would not be considered acceptable emissions control since any toxic substances in the gas would still be released to the atmosphere (T.D. Nos. 10 and 15). Passive systems can also constitute safety hazards, especially in areas where there is a likelihood for trespassing and there has been some consideration for posting warning signs near these potential emissions sources and/or constructing taller vents to promote gas dispersion (T.D. No. 10). From a public relations point of view, the active systems have an advantage over the passive systems since the public "feels" more comfortable ("safer") as it sees or hears the blowers in operation (T.D. No. 10). As noted previously, the state of Wisconsin now requires passive gas systems at all LFs with the additional requirement that such systems can be

TABLE 16. PASSIVE SYSTEMS FOR LANDFILL GAS MIGRATION CONTROL (21, 23)

Control System	Description	Advantages	Disadvantages
Trench with granular backfill	Along all boundaries to completely enclose each site. Gravel backfill greater than 6.4 m. Depth: 6.1 m or to groundwater table or bedrock, whichever is less.	Low cost at depths up to 3.7 m. Little maintenance is required. The granular backfill provides a highly permeable region venting to the air to allow low-resistance passage of gas.	Costs escalate rapidly at depths greater than 6.1 m. The barrier may not be effective if pervious natural soil layers exist on the outside of the trench. Gas could migrate and/or diffuse across the barrier. Difficult to construct at depths greater than 9.1 m and impractical to construct at depths greater than 14 m. Not controllable.
Trench with synthetic membrane liner (See Figure 7)	Along all boundaries to completely enclose each site. Synthetic liner, 30-mil thickness. Depth: to groundwater or unfissured bedrock.	Low costs at depths between 3.7 and 9.1 m. The membrane can provide a positive seal and be a barrier against gas and leachate. Little maintenance is required. Granular backfill on the landfill side of the membrane allows methane gas to vent to the air.	Costs become exceptionally high below a 9.1-m depth. The barrier may not be effective unless it extends into the groundwater table to eliminate gas migration beneath the membrane. Difficult to construct at depths greater than 9.1 m and impractical at depths greater than 14 m. Not controllable.
Natural induction wells	Perimeter and interior spaced same as forced induction wells. Depth: same as above.	Can install at depths greater than 30.5 m. Can cover a large area. Negligible maintenance and comparatively low operating costs.	Localized venting of methane. Large number required to achieve control of migration. Is uneconomical. Reliability and effectiveness have been inadequate. Not controllable.
Natural induction wells with subsurface collector pipes.	Perimeter and interior same as forced induction wells. Depth: same as above.	Can install wells to depths greater than 30.5 m. Can install collector pipes at varying depths. Can cover a large area of landfill surface using interconnecting collectors between wells. Negligible maintenance and operating costs.	Extensive piping and well system is needed at high cost. Reliability and effectiveness may be unsatisfactory, since this system basically combines the trench and well systems. Not controllable.

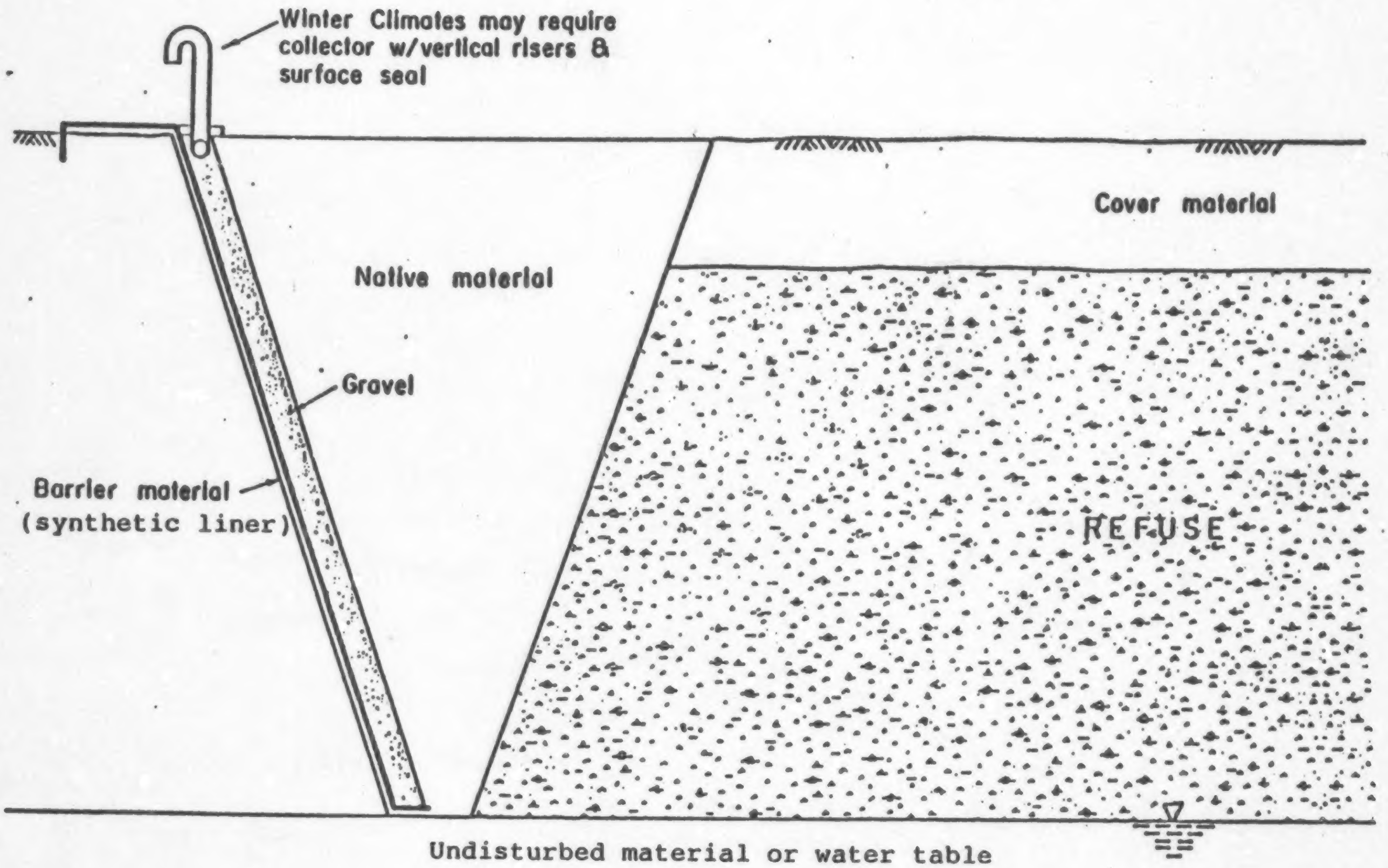
Winter Climates may require collector w/vertical risers & surface seal
Cover material
Native material
Gravel
Barrier material (synthetic liner)
REFUSE
Undisturbed material or water table

Figure 7. Trench barrier system for gas migration control (21)

TABLE 17. KEY FEATURES OF ACTIVE LF GAS EXTRACTION SYSTEMS FOR GAS RECOVERY AND/OR MIGRATION CONTROL (23, 55, T.D. No.1)*

Control	Description	Advantages	Disadvantages
Vertical gas extraction wells-interior	Designed to create a zone of negative pressure within the LF to collect decomposition gases. Usually spaced about 60 meters on center.	Gas from interior wells has a high methane content and can be used in a number of onsite or offsite energy recovery operations. This type of well has also been used for odor control on slope faces of LFs. Has been demonstrated at over two dozen LFs in the U.S.	Relatively costly and requires periodic maintenance. Wells cannot be established before LF is closed. Special precautions are necessary for drilling into waste. Wells can be damaged by local settling of waste.
Horizontal gas extraction wells-finished lifts	Short sections of pipe connected with loose fitting sleeves are placed within horizontal gravel trenches on finished lifts of an active LF.	A grid work of such trenches can cover the entire surface of a lift and capture significant quantities of gas migrating toward the LF surface. Additional lifts of waste can be placed over these trenches without impeding collection efficiency. The major advantage to this type of well is that gas can be recovered prior to completion of the LF and a greater portion of the gas can be captured than with vertical wells installed after completion.	Potentially subject to compression damage from equipment operating on lift and from settling of refuse. Cannot be readily repaired once damaged. Limited experience to data with the system.
Vertical gas migration prevention wells-periphery	Designed to create a zone of negative pressure between LF and neighboring properties. Spacing usually about 30 meters on center.	Periphery wells are effective in dry porous soils surrounding a LF Drilling in undisturbed soil is safer and less expensive than drilling into waste. Periphery wells can be established prior to closure of the LF. Has been demonstrated at a large number of LFs in the U.S.	When soils are wet or relatively nonporous, the radius of influence is small. Collected gas has considerable air content which limits energy recovery options.
Horizontal gas migration prevention wells-periphery	Consists of horizontal pipe buried in coarse gravel along the corner of a LF formed by the bottom and excavated side of the fill.	Permits gas removal from the bulk of the refuse as soon as it begins Gas flow can be regulated to capture reasonably air-free gas. Drilling into the refuse is not necessary.	Requires integration with leachate collection system. care must be exercized during emplacement of the first lift to avoid damage. Difficult to repair if clogged or damaged. Limited experience to date.

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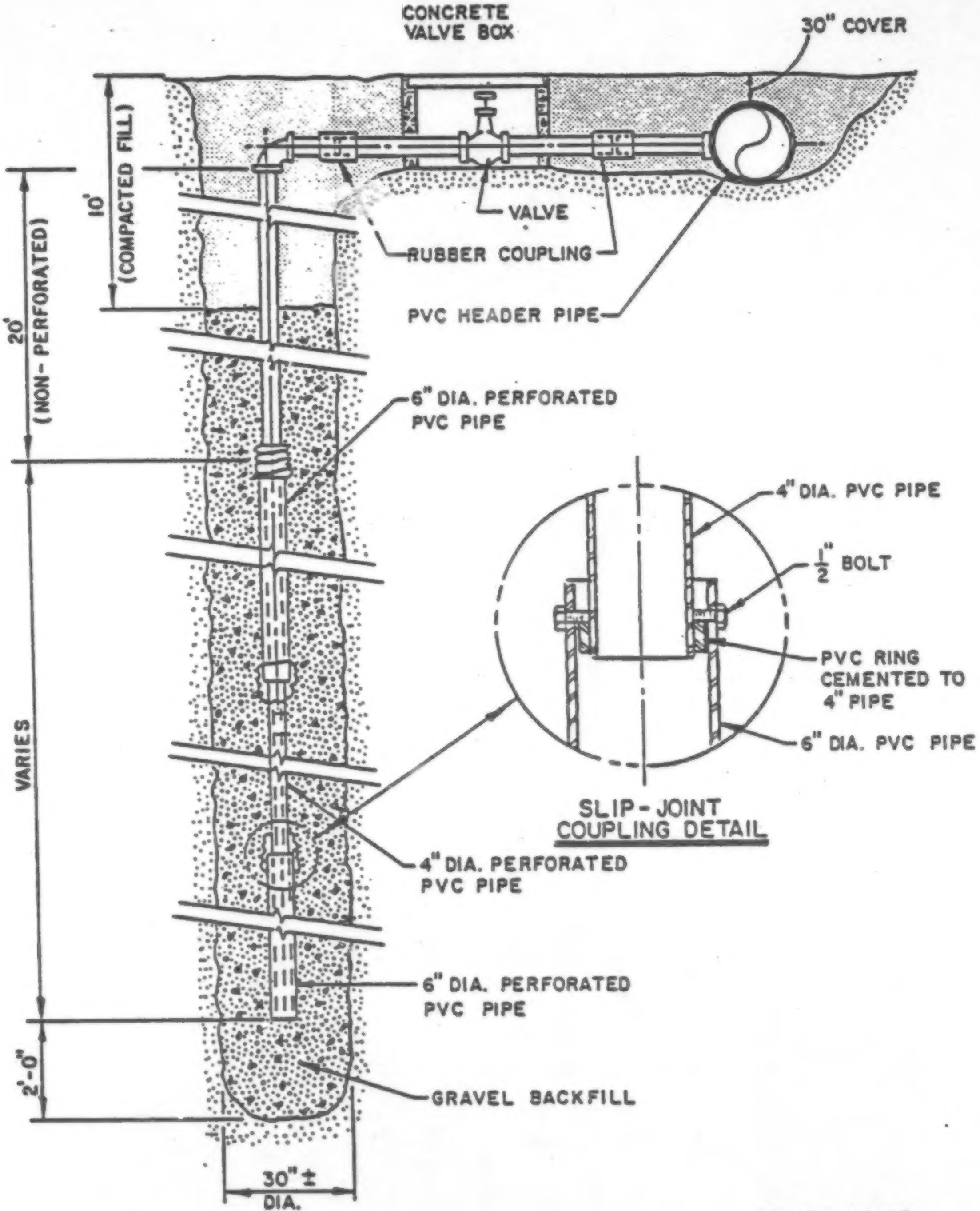
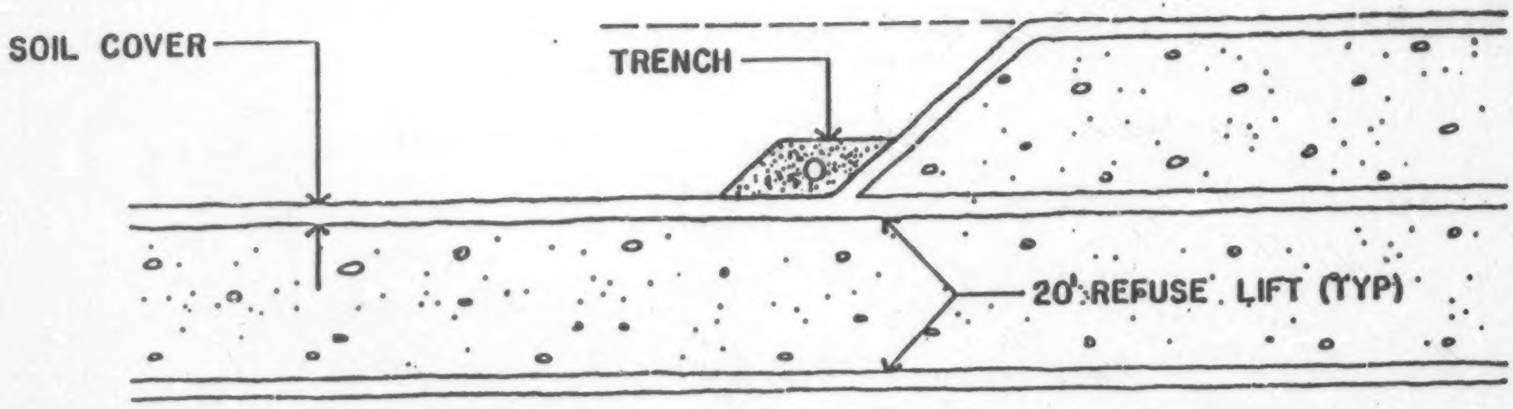
*See Figures 8 and 9 for schematic representation of these measures.

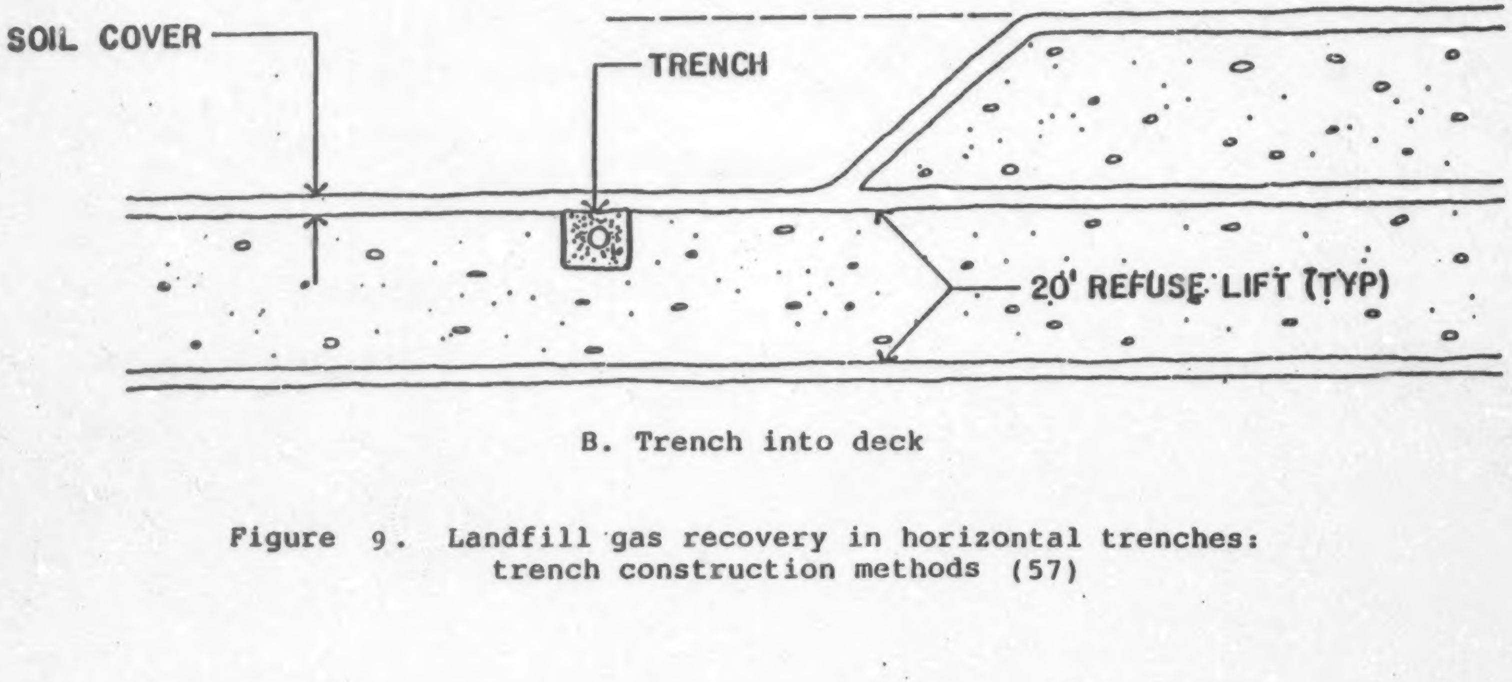

CONCRETE VALVE BOX
30" COVER
10' (COMPACTED FILL)
20' (NON-PERFORATED)
VALVE
RUBBER COUPLING
PVC HEADER PIPE
6" DIA. PERFORATED PVC PIPE
4" DIA. PVC PIPE
1/2" BOLT
PVC RING CEMENTED TO 4" PIPE
6" DIA. PVC PIPE
VARIES
SLIP-JOINT COUPLING DETAIL
4" DIA. PERFORATED PVC PIPE
6" DIA. PERFORATED PVC PIPE
2'-0"
GRAVEL BACKFILL
30"± DIA.

NOT TO SCALE

Figure 8. Schematic drawing of vertical gas extraction well (56)


SOIL COVER
TRENCH
20' REFUSE LIFT (TYP)

A. Place at side toe of lift


SOIL COVER
TRENCH
20' REFUSE LIFT (TYP)

B. Trench into deck

Figure 9. Landfill gas recovery in horizontal trenches: trench construction methods (57)

converted to active systems if necessary (T.D. No. 9).

As noted in Table 16, passive systems can incorporate use of synthetic liners (or other types of liners such as admixes and clay soils) for containing gas flow. Polyvinyl chloride (PVC) liners are frequently used because they are more impermeable to methane in comparision to materials such as polyethylene and are relatively inexpensive (21). As with uses in connection with landfill lining and closure, the integrity of the installed liner is critical and the liner must be put down to avoid puncture, and usually layers of sand or soil must be placed on both sides.

While effective in controlling convective gas flow, even the best passive systems which employ synthetic liners would not be totally effective in controlling diffusive gas flow. Even though synthetic liners have often been referred to as "impermeable" liners, and depending on the type and characteristics of the liner, some amount of gas would be expected to diffuse through the synthetic liner and into the surrounding soil. Haxo et al (53) have reported on laboratory measurements of the permeability of polymeric membrane lining materials. Permeabilities to three gases of interest (carbon dioxide, methane and nitrogen), water vapor and five solvents (methanol, acetone, cyclohexane, xylene and chloroform) were measured for a broad range of commercial polymeric membranes, primarily those used in waste management applications. Data for permeability at 23°C of a series of liners to the three tested gases are presented in Table 18 on both the basis of the gas transmission rates which are indicative of liner performance and on the basis of permeability coefficients which are material properties and reflect the permeabilities of the liner compounds. Haxo et al (53) concluded that:

- There are major differences in permeability among the membranes reflecting variation in polymer type, compound composition, and thickness.
- Permeability of polymeric liner materials can differ for a given generic polymer type due to compound variation (e.g., filler and plasticizer contents).
- Permeability of a membrane can differ greatly with the gas.
- Gas transmission of a membrane decreases with increased thickness.
- Higher polymer crystallinity yields lower permeability, as shown when comparing LDPE, LLDPE (linear low-density polyethylene), and HDPE.
- Permeability of polymeric membranes to gases increases with temperature in accordance with Arhenius equation.

TABLE 18. PERMEABILITY OF POLYMERIC MEMBRANE LINERS TO GASES AT 23°C DETERMINED IN ACCORDANCE WITH ASTM D1434, PROCEDURE V (53)

Liner Description				Gas Transmission Rate (GTR), mL(STP*)/sq m.d.atm			Gas Permeability Coefficient (P̄), barrer†		
Polymer	Liner Serial No.‡	Thickness mm	Compound type§	CO2	CH4	N2	CO2	CH4	N2
Butyl	44	1.60	XL	512	120	19.7	12.5	2.92	0.480
CPE	77	0.72	TP	106¶	6.31¶	1.45¶	1.16¶	0.065¶	0.016¶
CSPE	6R	0.82	TP	122	21.6	26.2	1.52	0.270	0.33
CSPE	55	0.86	TP	418	124	27.1	5.47	1.62	0.36
ELPO	36	0.58	CX	1450	280	125	12.8	2.47	1.10
EPDM	83R	0.89	TP	2720**	-	-	36.8**	-	-
EPDM	91	0.90	XL	5260	1400	314	72.0	19.2	4.30
EPDM	8	1.50	XL	-	470††	-	-	10.7††	-
Neoprene	90	0.90	XL	716	80.9	31.1	9.81	1.11	0.43
PB	221	0.71	CX	818	248	62.3	8.84	2.68	0.67
HDPE	265	0.61	CX	729	138	-	6.77	1.28	-
HDPE	269	0.86	CX	467	104	-	6.11	1.36	-
LDPE	21	0.25	CX	6180**	1340**	-	23.5**	5.10**	-
LLDPE	281	0.46	CX	1370	322	-	9.59	2.25	-
PVC	93	0.25	TP	7730**	1150**	-	29.4	4.38**	-
PVC	88	0.49	TP	3010	446	108	22.4	3.32	0.81
PVC	59	0.81	TP	2840**	285**	-	35.0**	3.51**	-

*STP = Standard temperature and pressure

†One barrer = 10^{-10} mL(STP).cm/cm^2.s.cm Hg

‡Matrecon liner serial number; R = Fabric-reinforced

§XL = Crosslinked; TP = Thermoplastic; CX= Partially crystalline

¶Measured at a pressure gradient of 40 psi; all others measured at 20 psi

**Measured at 30°C

††Measured at 20°C

It should be noted that the gas permeability data such as those presented above as well as similar laboratory-generated permeability data for landfill leachate constituents (e.g., reported in Ref. 54) may be substantially different than the actual leakage rates experienced in the field. This would be due to the differences between the field conditions and the laboratory conditions under which the permeability is measured (e.g., steady state conditions and use of clean, unsupported liner specimens). As pointed out by Haxo et al (53), in actual service a membrane liner is placed on a porous layer (e.g., soil or geotextile), the permeability of which can range greatly. Also, a liner is often covered or becomes covered with soil, sand or sludge. These materials will tend to retard the transmission of waste constituents. Thus, the transmission rates indicated in Table 18, even though very low, may be viewed as representing the upper limit (worst-case) conditions.

Active gas systems use blowers to collect gas through a network of extraction wells and/or trenches. The collected gas is either disposed of by flaring (which may often require the use of supplementary fuel) or combusted (e.g., in turbines) for energy recovery. In either case, a high degree of destruction of toxic organics can be achieved when combustion temperatures are kept at about 800°C or greater. Carbon adsorption units can in principle be used in conjunction with both passive and active systems to remove toxic organics from the landfill gas. However, as noted in Section 5.2, the reported experience with the use of carbon adsorption for gas control has been very poor due to maintenance problems and the difficulty in estimating when the carbon needs changing or reactivation. When control of the landfill odor is of primary concern (e.g., in Southern California), excess air is sucked in through the landfill cover and this can reduce the heating value of the gas and hence affect the choice of the energy recovery method (e.g., power generation in turbines vs. upgrading of gas to pipeline quality).

The technology for gas collection and flaring (and to a lesser extent, for recovery of energy from landfill gas) are well established, and a number of manuals and guideline documents are available covering the design and operation of such systems (e.g., Refs. 21-23). The detailed application of these techniques and their economics tend to be highly site-specific, since environmental conditions and gas yield vary greatly among landfills (T.D. No. 16). Gas recovery from landfills, including potential problems and opportunities, has been the subject of several recent workshops and symposia (e.g., Refs. 58-60). Much of the current research and development and full scale testing activities are aimed at improving energy recovery systems and equipment designs and identifying potential long-term operating problems (e.g., equipment corrosion). For example, at Puente Hills LF in Southern California, where gas is collected and used to generate power serving the electrical needs of approximately 5,600 homes, two dissimilar turbine designs are under evaluation to determine comparative performance and reliability in the landfill gas application (61). Substantial combustor and fuel systems modifications were required to allow operation on landfill gas, given that industrial gas turbines are normally designed to operate on natural gas, which has three times the heating value of the landfill gas at Puente Hills.

5.5.2 Surface Impoundments

Although actual data on their extent of use and effectiveness are not available, there are a number of measures for reducing SI emissions. These measures, which are described briefly in Table 19, may be classified as preventive or corrective depending on whether they are incorporated features of the original design or are implemented after the problem has surfaced. Proper siting and source control are considered by some (see Section 5.4.3) to be the most viable approach for reducing emissions. Source control involves reducing the concentration of volatiles in the raw wastewater or the potential for their emissions through in-plant controls (e.g., process/equipment selection or modification, waste segregation, material recovery, operating considerations and good housekeeping) and/or wastewater pretreatment (e.g., via solvent extraction or distillation to remove VOCs).

Floating covers have been successfully used for water supply reservoirs (e.g., to reduce high levels of coliform bacteria and maintain chlorine residuals in the water systems (62). These covers have recently been considered for use to prevent overtopping of SIs by rain and snow (16, 63). A range of patented reservoir cover designs are available (64). Most designs feature sump systems for collection and removal of precipitation. Figure 10 shows schematics of a simple design, referred to as "untensioned, centrally floated, peripheral sump reservoir cover" (or UCFPSR), for a sloped-sided rectangular reservoir. the plan view shows the network of floats beneath and attached to the cover (bold line in the center). Usually the central float is placed down the longest axis of the reservoir, with the parallel floats running perpendicular from the central float, spaced 20 to 30 ft apart. It is intended that this central portion will form a series of parallel paths which direct rainwater to the peripheral space outside of the centrally-floated area and inside the perimeter of the reservoir. This is intended to form a peripheral sump between the central float portion and the anchor means at the perimeter of the reservoir. The cross-sectional view of this reservoir in Figure 10 shows the UCFPSR Cover as the reservoir goes from the empty state to the full state, with both the peripheral sump substantially full (rainwater not removed from the sump area) and substantially empty. Figure 11 is a

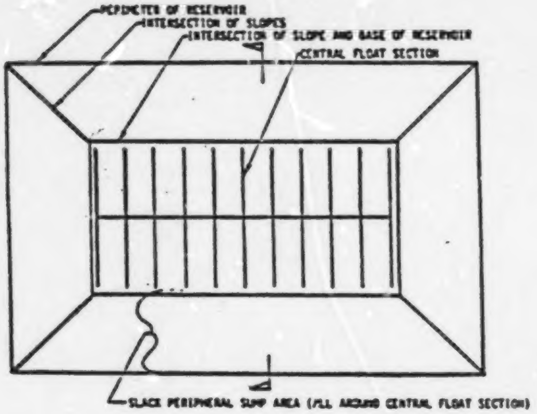
TABLE 19. PREVENTIVE/CORRECTIVE MEASURES FOR VOLATILE EMISSIONS FROM SURFACE IMPOUNDMENTS

Control Measure	Description	Advantages	Disadvantages
Source Control	Pretreatment of waste segregation to minimize volatiles content of incoming waste to SI. Temperature reduction may also be applicable for warm influent.	Minimizes or eliminates the need for add-on controls. Can be the most cost-effective approach in some cases.	Not feasible for some waste streams and/or some volatile constituents. Commonly, easier to implement at newer facilities than at older ones.
Site Location	Locating SIs away from and/or downwind of areas with a high potential for human exposure (e.g., residential or light commercial zones). Consideration of natural winds and wind barriers in selection of a site.	Can minimize levels of toxic substances in ambient air where persons are exposed. Can minimize odor complaints.	May not necessarily reduce absolute emissions levels.
Side Enclosure (with or without add-on vent controls)	Rigid or inflatable cover over SI; use of covered tank system.	Emissions are confined to air space above liquid surface and within the enclosure. Equilibrium vapor pressure will be approached for volatile waste compounds, with little additional volatilization. Source enclosure of aerated systems, with control of overhead gases via activated carbon or incineration offers the greatest potential for volatile emissions reduction.	Impractical for large SIs. Without further controls, breathing losses may occur. Not applicable to evaporation ponds.
Floating Cover	Blanket of plastic or other flexible material suspended on surface of SI.	Reduces wind-induced turbulance of the SI surface and decreases area exposed to atmosphere. Less expensive than enclosure.	Impractical for large SIs. Covers are subject to damage by winds. Unless selected of suitable materials, covers may also be subject to degradation by waste and UV light. Not applicable to evaporation ponds.

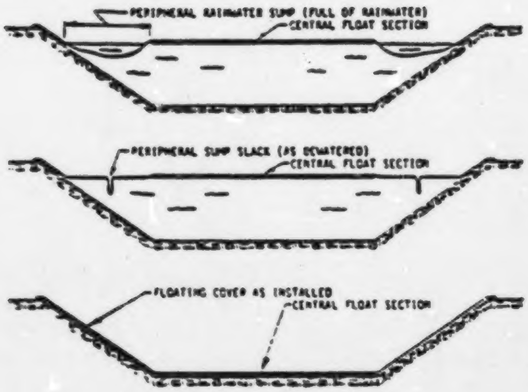
(Continued)

TABLE 19. (Continued)

Control Measure	Description	Advantages	Disadvantages
Surface Films	Thin floating layer of immiscible liquid (e.g., mineral oil) placed on SI surface. Serves as a physical barrier to volatilization.	Can reduce emissions of compounds which are more soluble in water than in the film liquid. Not subject to physical damage as is a plastic floating cover.	May not be effecive for organics which are more soluble in the organic liquid than in water. May require separation of organic liquid from water prior to discharge. Not suitable for aerated systems, in heavy winds, or for evaporation ponds.
Competitive Solvent Phase	Mixing an immiscible solvent with wastewater.	Can reduce emissions of compounds which are more soluble in solvent than in water. Not subject to physical damage as is a plastic floating cover.	Recovery, treatment and disposal of solvent which contains volatile compounds may be required. Forced mixing may be necessary to effect extraction of target organics from the aqueous phase. Not applicable to evaporation ponds.
Wind Fences	Wood, plastic, metal, or vegetative fences to deflect and/or disperse winds around an SI.	Can reduce wind-induced turbulance of the SI surface. Relatively inexpensive and maintenance free. May also improve visual appearance.	Effectiveness highly site-specific.


PERIMETER OF RESERVOIR
INTERSECTION OF SLOPES
INTERSECTION OF SLOPE AND BASE OF RESERVOIR
CENTRAL FLOAT SECTION
SLACK PERIPHERAL SUMP AREA (ALL AROUND CENTRAL FLOAT SECTION)

A. Plan-view


PERIPHERAL RAINWATER SUMP (FULL OF RAINWATER)
CENTRAL FLOAT SECTION
PERIPHERAL SUMP SLACK (AS DEWATERED)
CENTRAL FLOAT SECTION
FLOATING COVER AS INSTALLED
CENTRAL FLOAT SECTION

B. Cross-sectional view

Figure 10. Schematic of a UCFPSR cover (64)

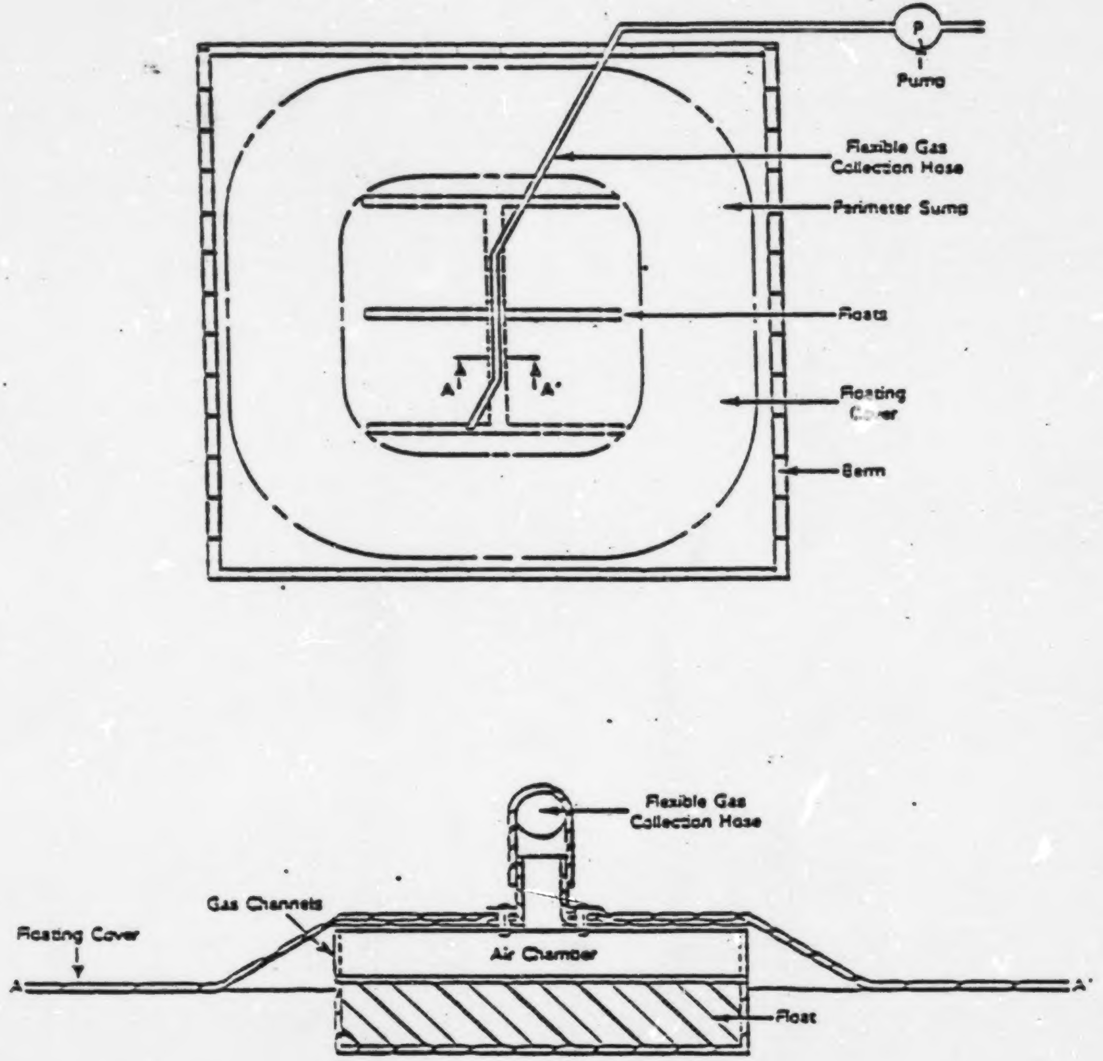

P
Pump
Flexible Gas Collection Hose
Perimeter Sump
Floats
A
A'
Floating Cover
Berm
Flexible Gas Collection Hose
Gas Channels
Floating Cover
Air Chamber
A
A'
Float

Figure 11. Schematic overview and cross section of a patented floating cover with gas collection system (63)

schematic of a floating cover with provisions for removal of gas accumulating underneath the cover.

The study referenced above on the applicability of floating covers to SIs for the purpose of preventing overtopping by rain and snow included a state-of-the-art review of the floating covers. The review, which was based on the very limited data available in the literature, patent descriptions, and information obtained from several manufacturers and installers of floating covers, indicated the following (63):

> At the present time, Globe Linings has installed approximately 200 covers while Burke and five other companies have installed about 100 more. These covers usually range in size from about 15,000 sq ft to about 700,000 sq ft. Larger covers have been made. One cover, now under construction in the Los Angeles, California area, spans 2,000,000 sq ft.
>
> According to industry officials, approximately 80 to 85 percent of all floating covers have been constructed over potable water reservoirs. The remaining 15 to 20 percent have been used on biodegradation facilities, at slaughtering houses, on chemical treatment ponds, on toxic waste lagoons and on fish hatchery ponds. The covers for biodegradation facilities were developed to collect methane gas for use in boilers or electric generators. Odor control is the main purpose cited for covering pits at slaughtering houses. Fish hatchery ponds are covered to prevent algal blooms which can kill fish. Covers on chemical treatment ponds and toxic waste lagoons were used to prevent overtopping due to precipitation. Very little data were available on the types of chemicals or facilities involved in covering waste lagoons due to the proprietary nature of these activities.

The applicability and effectiveness of floating covers and other controls shown in Table 19 are very waste- and site-specific. Some measures (e.g., source enclosure or use of floating covers) would most likely be inapplicable to (or not economical for) very large impoundments or where SIs are to serve as evaporation disposal ponds. Also, at the present time there is very little experience with the use of these systems in full scale facilities. Moreover, unless the volatile constituents in the wastewaters are biodegraded or modified, or collected and destroyed (e.g., via incineration of overhead vapors), the emissions control for SIs may only serve a temporary purpose and the problem is accumulated or transferred to some downstream treatment systems. When the discharge to an SI is on an intermittent basis (e.g., from batch operation), and depending on the system design, some degree of control may be exercised through scheduling to avoid discharge or operation under unfavorable weather conditions. Maintaining aerobic conditions in some ponds (through supplemental aeration and/or chemical addition) may also be applicable for odor control at some SIs.

A number of EPA studies are currently in progress to evaluate emissions control technology needs and effectiveness for SIs. One study, which involves engineering and economic analysis of alternative add-on controls, is being carried out by Arthur D. Little (ADL) Corporation for EPA's Office of Air Quality Planning and Standards (OAQPS). In another study, Research Triangle Institute (RTI) is evaluating effectiveness of wastewater pretreatment as a control method for SIs.

5.6 RESEARCH AND DEVELOPMENT NEEDS

As noted previously, the very limited actual emissions monitoring which has been carried out at a number of closed hazardous waste landfills indicates insignificant emissions from such sites (certainly in comparison with emissions from waste treatment and open disposal activities which are part of the operation at such sites). Similarly, surface impoundment emissions, which have been measured at only a very few sites, have been very low, generally near the detection limits of the sampling and analytical methods used. The representativeness of the facilities included in these limited surveys is not known. Thus, establishment of the representativeness of the available data, which may necessitate emissions measurements at additional sites, appears to be an area for further R & D.

The need for additional field data was especially emphasized by some state agencies with whom technical discussions were held (see Section 5.2.2). While recognizing the desirability of developing predictive emissions models for regulatory purposes, some researchers (e.g., Ref. 65) point out that the models which have been developed require too many inputs which are difficult to accurately define and that models (the simple ones) can best be only used to obtain rough, order of magnitude ideas and hence R & D effort should place a greater emphasis on collection of field data than on development of new models or refinement of models which have been shown to yield estimates differing from actual measurements by several orders of magnitude. R & D efforts to develop emissions controls for SIs should also emphasize realistic conditions and testing in large-scale or actual facilities. Source testing to determine emissions and evaluate effectiveness of controls may require further development and refinement of specialized techniques and protocols (e.g., for sampling emissions from leachate standpipes --see T.D. No. 12).

From the standpoint of emitting toxic and reactive substances to the atmosphere, municipal and co-disposal sites can conceivably have a greater total impact on the environment than HWLFs. Accordingly, the nature of emissions from the municipal and co-disposal sites and their air quality significance need to be assessed (T.D. No. 16). Although some assessments have been made by the private sector, much of the data base for the assessment is not publicly available. If municipal and co-disposal landfills are determined to be major emission sources, active gas extraction may prove the most cost-effective control method. To promote gas recovery from landfills, it may be necessary to introduce some flexibility in the existing regulations (see T.D. No. 16). The kind and extent of necessary regulatory changes need to be studied.

From a design optimization viewpoint, and in the light of the data presented in Table 15, parametric evaluation, in full-scale "real world" facilities, of various cover systems for landfills from the standpoint of emissions control effectiveness has been suggested (T.D. No. 4). Parameters to be evaluated in such studies should include soil type, density, organic content, moisture level, etc. Such studies can provide the basis for tailoring cover design and maintenance procedures to specific locational/geographic requirements (T.D. Nos. 1 and 4). In connection with cover system design, investigation of the effect of landfill gas and volatile substances on FML covers has been suggested as an item for R & D (T.D. No. 2).

Some of the R & D needs discussed in Section 4 in connection with the leachate management system (e.g., investigation of novel design concepts, documentation and dissemination of experience from full scale facilities, better characterization of the type of wastes which are now sent to disposal facilities and the expected future trends) would also be applicable to landfill gas management and are not repeated here. A number of other gas- and emissions-specific R & D recommendations provided by various individuals with whom discussions were held in the present study are as follows:

- Investigation of how the refuse mass behaves in the landfill environment from the standpoint of permeability to gas (T.D. No. 10).

- Evaluation of impact of impurities in landfill gas streams (e.g., heavy metals and halogenated compounds) on its potential uses (T.D. No. 3).

- Assemblance of information on models that predict gas generation rates and verification of models using results from actual field monitoring (T.D. No. 3).

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APPENDIX A

TECHNICAL DISCUSSION (T.D.) REPORTS

A.1 TECHNICAL DISCUSSION NO. 1

Sanitation Districts of Los Angeles County: Raymond Huitric
James Lu

MEESA: Masood Ghassemi, Michael Haro

April 13, 1984

Leachate Collection

- Because of the unique features of the six landfills under the jurisdiction of the County Sanitation Districts of Los Angeles County * (hereafter referred to as the Districts), and the special strategy which the Districts uses to minimize leachate generation (see below), no leachate has been observed in any of the leachate collection systems for these landfills. Some liquids which have been noted are believed to be perched or spring water which has been intercepted. Because leachate collection systems do not carry leachates and are employed primarily as a precautionary measure, no problems have been noted or are anticipated with the leachate collection systems at the Districts' facilities. Such problems are more characteristics of the sites in the East and those not governed by strict regulations on waste handling and placement practices. There have been some occasional problems with the accumulation of silt/sand in the collection wells. But the problem has been easily corrected through simple cleanout of wells.

- The landfills under the Districts' jurisdiction are very unique from the standpoint of location, topography and climate (i.e., the low precipitation and high evaporation

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* The six Districts' landfills are Calabasas, Mission Canyon, Palos Verdes, Puente Hills, Scholl Canyon and Spadra. Of these, only Palos Verdes (now closed) and Calabasas sites have received hazardous wastes and are co-disposal sites. Calabasas site no longer accepts hazardous waste and is now a strictly municipal waste disposal site. The other four are considered municipal refuse sites.

rates, the significant distance to ground water and disposal in canyons/ravines as opposed to in excavated land or on flat ground). Because of these features, it is possible to prevent leachate formation at these sites. To achieve this, the Districts rely on the following strategy:

-Use of french drains to intercept subsurface drainage (i.e., perch water or spring water). In newer designs, a double drainage system (see Figure 12) has been employed to intercept the spring water or perch water (which, incidentally, can exert a significant pressure on the liner) and to remove any leachate. Both drain systems are connected to a single collection pipe which discharges into public sewers.

-Use of leachate barriers and extraction systems in conjunction with french drains to intercept any leachate formed.

-Limiting liquids and dewatered sludge disposal in landfills. In the past, liquids were accepted at some landfills (e.g., Palos Verdes) to the extent that the amount admitted would remain far below the absorptive capacity of the refuse. (This previous approach can still be utilized when a liquid waste is solidified or mixed with absorbents).

-Designing, constructing and maintaining covers which minimize infiltration. Although a material with a permeability of 10^{-8} to 10^{-7} cm/sec is considered suitable as cover material, the permeability is viewed as only one of the several factors which determine the effectiveness of a cover design. Other factors include thickness of the cover and climatic conditions, which should be considered in a water balance analysis to determine optimum design. The cover at the Palos Verdes landfill consists of 5-ft. of 10^{-8} to 10^{-7} cm/sec permeability clay. There is a temporary irrigation system which can be removed when appropriate vegetation cover has been established.

-Because California conditions and vegetations are different than those elsewhere, specific cover maintenance procedures developed elsewhere would not be applicable here. Accordingly, the Districts has a plan to undertake a 1 to 2 year field study to determine the type of vegetation and irrigation system which can maintain a cover, but yet prevent water percolation into the waste fill.

- There is little guidance on leachate drainage system design in the open literature.

Gas Control

- The Districts has been the pioneer in extracting gas from

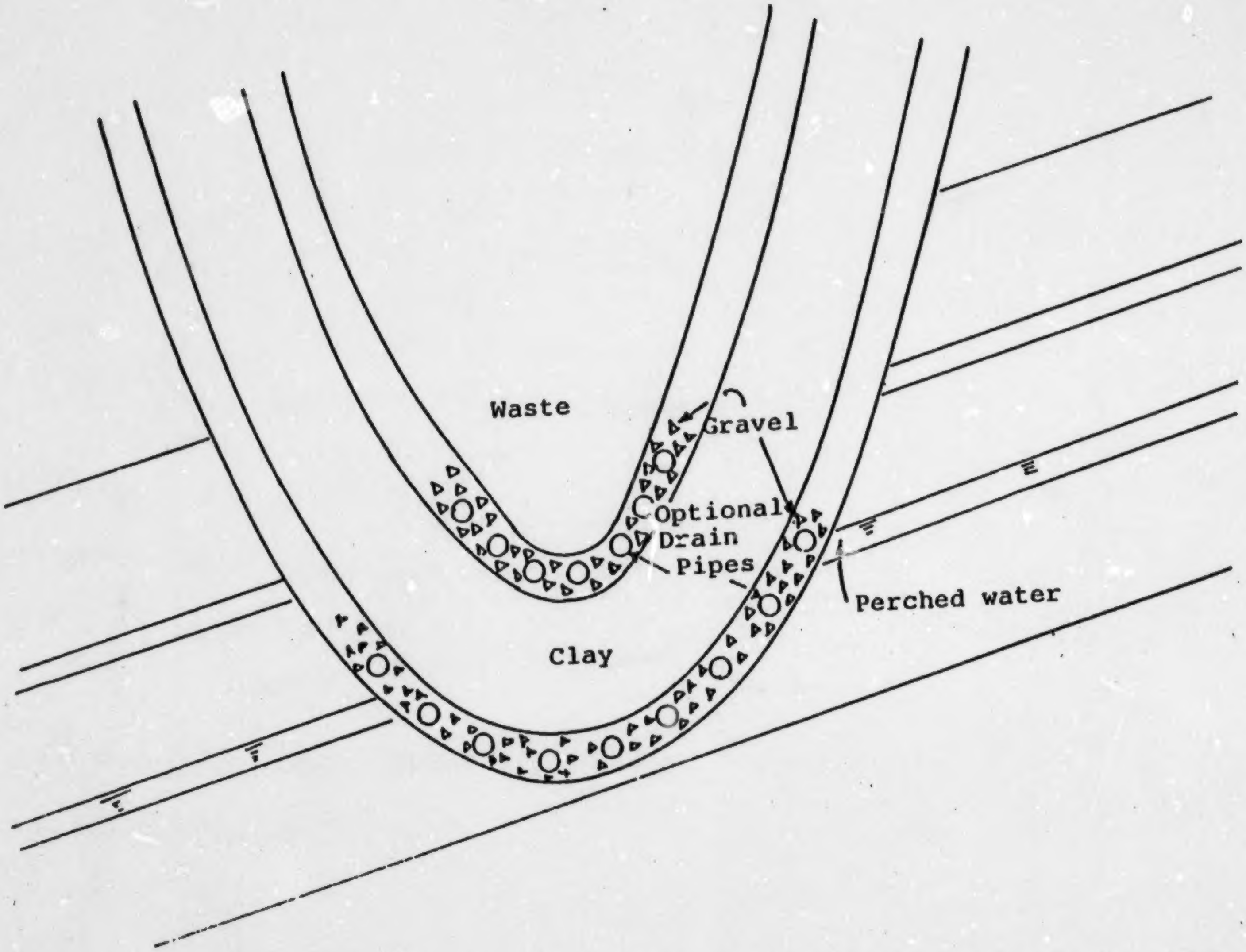
Waste
Gravel
Optional
Drain
Pipes
Perched water
Clay

Figure 12. Sketch showing the use of a double-drainage system for leachate collection and interception of perched or spring water

landfills and all six Districts' landfills have or soon will have (by year end) gas collection systems.[*] By maintaining a vacuum in the collection system and designing a collection system of sufficient extent, an active gas control system would minimize atmospheric emissions. This was verified in a recent study for EPA by the Illinois Institute of Technology Research Institute (IITRI). The study involved air pollution sampling and analysis at hazardous waste facilities which included some of the Districts' sites. The collected data could not distinguish between upwind and downwind conditions.

- The gases recovered from Districts' sites are either flared or used as energy source. When the gas is flared, any volatile organics in the gas are destroyed. Current flare systems at the Districts' sites operate at a temperature of close to 1300°F; planned design modifications will increase the flare temperature to 1400 to 1500°F. At these temperatures, there should be little or no emissions of reactive organics. Emissions of halogenated organics is also not expected to be a problem and the emissions meet applicable Air Quality Management District emissions regulations. When the gas is used in turbines, corrosion can be a problem of concern which has to be mitigated through proper design (e.g., use of appropriate alloys or coatings) or via gas pretreatment. At the Palos Verdes landfill, the recovered gas is used in turbine for power generations. In a separate operation at this site, Getty Synthetic Fuels, Inc. uses activated carbon and molecular seive adsorption systems as part of a gas treatment system to produce substitute natural gas (SNG).

- Typical gas collection systems designed by the Districts in the past consisted of vertical wells and collection pipelines located in completed sections of the landfills. This approach avoids operational conflicts at the active landfill site. However, collection systems installed after completion of landfilling cannot prevent escape of odor during the operating life of the landfill. In addition, energy that may be recovered from landfill gas generated prior to completion of the landfill is lost. These two concerns are eliminated by use of a horizontal trench gas recovery system which has been developed and tested by the Districts. The new system consists of a network of pipelines laid horizontally in trenches within the buried solid waste and backfilled with one to two-inch size gravel. These trenches are constructed in the fill as the waste is placed, or shortly thereafter, thereby providing odor control (and energy recovery) prior to completion of the fill.

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[*] Gas collection systems for Calabasas and Spadra sites are under construction.

- A vertical trench interval such as 80 ft and a horizontal trench interval such as 300 ft are being considered for installation at the Puente Hills landfill. The pipelines will be installed with frequent slip joints to allow for settlement. Gas will be withdrawn from surrounding waste after a lift (18- to 25-ft layer) of waste is placed over the trench system. The pipes within the gravel trenches will be connected to header collection pipelines located along the outside slopes of the landfill. These pipelines will deliver gas from the trenches to the energy generation facilities and/or flaring stations. The construction of the trench system is coordinated with and part of the daily landfill operation.

- Properly designed and constructed soil covers can be effective in preventing landfill emissions. The available information indicates that both adsorption and biological activity in the soil are responsible for emission control. At its Palos Verdes landfill, the District has made numerous odor measurements and has determined several orders of magnitude reduction in the odor as the gas passes through the cover. The reduction in odor is believed to be due to aerobic biological activity within the cover.

Waste Handling

- Suitable waste handling and placement procedures (e.g., waste segregation, removal of incompatible wastes, etc.) and appropriate methods for ensuring compliance with these procedures (e.g., use of on-site inspectors and radiation monitors, manifest system, laboratory testing of randomly selected samples, etc.) have been well developed and extensively discussed in the literature.* Waste placement practices, however, can impact air emissions control and leachate management effort and for the purpose of our study should receive attention in that context.

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* For example, the following documents include discussions of waste handling and inspection procedures and the results from such effort:

-"Control of Infectious, Hazardous and Radioactive Waste Disposal at Puente Hills Landfill", a report summarizing the Districts 'effort at the subject site, dated Dec. 2, 1983.

-Van Heuit, R. E., "Disposal of Hazardous Waste and Industrial Residues in Sanitary Landfills", paper presented at the California Water Pollution Control Association, Southern Reg. Ind. Waste Conf., Airport Marina Hotel, Dec. 9, 1976.

- In the past, waste solvents were segregated and separately disposed of in the Palos Verdes landfill using injection wells. This approach, however, is no longer considered suitable and is not practical at any of the Districts' sites, as it is felt that solvents will gradually volatilize from the landfill and it is better to dispose of them by other means (e.g., incineration or reclamation). Emissions resulting from past solvent injection practices are minimized by use of gas extraction systems.

Miscellaneous

- The issue of liner-waste incompatibility has been somewhat blown out of proportion by results from studies which have used test solutions (e.g., pure organic solvents) having little resemblance to wastes and leachates which actually come in contact with the liner in a "real world" facility. At the Districts' sites, there is very little chance for a waste solvent to come in contact with the liner, since there is a 25-ft. depth of fill (refuse) before any hazardous waste is placed in a landfill; any hazardous waste released will be absorbed by the 25-ft. depth of fill. The leachate (if any) which may reach the liner is also a very dilute aqueous solution containing organics in the ppm levels.

A.2 TECHNICAL DISCUSSION NO. 2

CH2M-Hill Larry W. Well

MEESA: Masood Ghassemi, Michael Haro

16 April 1984

(Note: Mr. Well is a recognized expert on liner design. At CH2M-Hill he functions as a "consultant", providing advice on matters relating to liner design and placement. Accordingly, much of the discussion with Mr. Well centered on various aspects of liner design, installation and performance.)

Leachate Collection

- Mr. Well personally is not aware of any leachate collection system that has been clogged.

- The best way to manage leachate is to prevent its formation through proper site design and operating procedures.

- Most solvents are lighter than water and would not enter the leachate collection system as distinct phases. However, at the present time little is known about emulsion formation in the leachate and what levels of emulsions can be tolerated by the system.

- PVC pipes have been widely used in leachate collection systems because they are easier to work with and cost less compared to materials such as polyethylene which may have the advantage of being somewhat more resistant to chemical attack.

Gas Control

- When gas is to be contained (for recovery or odor control) through installation of an FML cover, PVC may not be the ideal cover material because of its potential susceptibility to chemical attack. In this respect, HDPE may be a preferred material due to its greater inertness. HDPE, however, is more difficult to work with and throughout the country there are perhaps only a handful of installers who can be trusted to do a good job of installing HDPE. CH2M-Hill has successfully used HDPE in a job in Idaho involving recovery of methane (and control of odor) in anaerobic digestion of potato processing waste.

Waste Handling and Placement

- Segregation of waste in subcells is very important from the standpoint of developing the best design and for operation control.

- There is no practical way to exert complete control over the actual disposal operation to ensure that restricted wastes are not accepted and that appropriate waste segregation and placement practices are followed. Use of manifests, inspection, and random sampling, although very effective, are not 100% fool-proof. Accordingly, it is best "to plan for the worst and hope for the best".

Leak Detection and Liner Repair

- Compartmentalization of operation and designs which provide for separate leak detection systems for individual compartments or subcells, can conceivably allow for the identification of a leaking subcell so that corrective measures can be limited to a smaller area rather than a very large cell or entire landfill. This, however, is not very practical for large landfills where cells and subcells would also be very large. Even if a leak is detected in a large facility, it would be prohibitively expensive to remove the waste in order to mend or replace the leaking liner. The design approach, however, is practical on a small scale and has been used by CH2M-Hill at a unique facility in Times Beach, MO for containment of PCB-contaminated soil. (The Times Beach facility has a 240 ft by 400 ft concrete floor, 14-ft concrete walls, spray-on membrane on top of concrete and polyurethane spray/foam on top of the membrane; the storage site has been subdivided into several cells, with each cell provided with its own leak detection system.

- Assuming that the leaks can be located, leak repair success depends on a number of factors such as type and age of liner and environment to which the liner has been exposed. For example, because Hypalon cures as it ages, it is not possible to properly patch a very old Hypalon liner; for a system which is only about one or two years old, it is possible to scrub the liner to get to the uncured material and thus obtain a good seal. HDPE, on the other hand, does not suffer from this aging problem.

- In inspecting and accepting a completed liner, it is virtually impossible to detect all leaks (unless they are major ones) through standard tests such as measurement of evaporation rates for use in water balance calculations. Inspection of the entire subsoil for "soft spots" is also impractical. Thus leak detection is very difficult even in clean systems, let alone for liners used in waste management applications. The best approach would thus be to strive for developing a leak-proof system in the first place. A rigorous QA/QC program, which includes use of reputable installers and third party inspection employing thorough and conscientious inspectors, is very essential in achieving an adequate installation. There are a large number of documented cases of liner leakage due to the owner "overtrusting" the installers and not carrying out an independent inspection.

- There has been some R&D work in Europe on potential animal damage to liners. Results indicate that PVC is possibly more susceptible to damage by rodents than an 80- to 100-mil HDPE. Apparently the odor of the new PVC liner is attractive to rodents. Burrowing animals are known to dig through concrete, and hence potential for similar damage to FML remains.

Miscellaneous Cover/Liner Considerations

- Use of FML instead of clay in some locations is dictated by economics. In certain geographic areas and at specific sites it may be too expensive to bring in clay or other specialty products such as bentonite. Sites with adequate in-situ clay are not very plentiful in the Northwest or in many western states (e.g., CA, OR, WA, UT, and AZ.). Also, clay may often be more difficult to work with; after a rain, clay may not be workable for sometime, whereas FML can be reworked as soon as the weather improves.

- For certain liners clean water can present a harsher environment than waste or leachate. For example, loss of plasticizer from PVC (due to leaching) is believed to be more pronounced in a clean water environment. Data from sewage ponds lined with bentonite clay appear to indicate an increase in liner permeability over time, probably due to the ion exchange effect whereby the sodium ions in the bentonite are replaced with the calcium and magnesium ions from the waste.

- Potential failure of the cover due to differential settlement is of greater concern than failure due to broad, uniform settling, as the latter can be adequately addressed in the design. Even if the liner can elongate 500% to 800% without failing, this extent of elongation may not be sufficient to absorb impact due to a major localized subsidence.

- Recent studies have shown the coefficient of friction of some FML materials like HDPE is low. This limits the placement of protective soil cover, as in landfill, to shallow slopes.

- One possible solution to the problem of keeping FMLs on slopes in high-wind areas is to put air vents on slopes. When the wind blows across vents, it creates a negative pressure under the liner and theoretically should hold the liner on the slope.

- Puncturing holes in liner "bubbles" which may appear in certain poorly-designed impoundments is not a corrective measure; such an action will not cause the raised liner to settle to its original position and will only further damage the liner. The volume under the bubble is largely liquid and may contain only a few percent gas.

- The experience with the use of FML in waste disposal applications is not very extensive. There have been major design errors in the past (e.g., not providing a protective cover for PVC liners), but the designers have learned from past mistakes and errors occur less frequently now than in the past. The pouring of concrete is a practice which is several centuries old, but still mistakes are made once in a while, producing a bad batch of concrete.

- CH2M-Hill has made a large number of liner installations for "clean" systems. Many of these installations have been in service for more than several years and the experience with them has been very good.

R&D Needs

- Evaluation of the use of geotextiles as a component of the leachate collection system and development of design criteria for such an application.
- Studies of the effect of landfill gas and volatile waste components on FML covers.
- Evaluation of the effectiveness of various methods (e.g., inducing ground vibration) for control of burrowing animals in the vicinity of lined facilities.
- Better method to measure leakage or leak test a completed facility.

A.3 TECHNICAL DISCUSSION NO. 3

CH2M-Hill M. Kennedy

MEESA: M. Ghassemi, M. Haro

17 April 1984

Leachate Collection

- Because there is no long-term experience with leachate collection systems for hazardous waste management applications, there are little data available to evaluate the performance of these systems. There is no clear definition of what constitutes clogging or a standard method for measuring leachate head, which has been used as an indicator of leachate collection systems' performance. Accumulation of leachate in the collection sump is not conclusive evidence that the system is functioning properly, since it provides no information on the rate of leachate flow. When the pattern of leachate flow has been well established over a long period of time, a substantial reduction in flow can be interpreted to indicate system clogging. The most direct method for assessing the system performance is perhaps through excavation and direct observation of the conditions of the lines and sand and gravel envelopes; this, however, is not a practical approach and could be very costly.
- Although we know, based on experience with sewer lines and agricultural drainage systems, how to clean up leachate collection pipes when there is major clogging, and the

designs provide for such cleanup contingencies, there is currently no practical way to clean up drainage envelopes consisting of sand, gravel, and/or stone if and when they become clogged. It would be very costly to replace the drainage media in a hazardous waste site. Excavation in a hazardous waste can also be very dangerous. There is no practical and economical method to replace even the piping system in a landfill which contains a substantial amount of waste. Thus, the only workable approach is thorough preventive measures such as incorporation of redundancies in design and execution of rigorous QA/QC during all steps leading to the development of a completed system (e.g., during construction, thorough inspection to ensure use of specified drainage aggregates, pipe slope, field tests, etc.).

- The conservative design philosophy and incorporation of redundancies in the leachate collection system is best illustrated in the following system designed for a commercial hazardous waste disposal firm by CH2M-Hill. This secure landfill, located in the Northwest, is situated 200 to 300 feet above the uppermost aquifer in low permeability soil; the average annual rainfall is 7 inches. Although design calculations indicated little leachate production could be expected, it was nevertheless designed for a worst-case scenario of 7 inches of rain occurring in a one-month period. The leachate collection system is designed to allow up to a maximum of 0.8 feet of head on the liner. The system consists of a 12-inch sand layer, a geotextile for separation, a 12-inch drain rock layer, 4-inch diameter perforated HDPE collector pipe, 6-inch diameter perforated HDPE header pipe, and leachate collection sumps, all over an HDPE and clay liner system. The header and collection pipe have a minimum slope of 2%; cleanouts are provided at the ends of each pipe and in the sumps.

Gas Management

- The most relevant CH2M-Hill experience with gas management problems is with a municipal landfill site in Oregon City, Oregon, where there were considerable odor complaints. Based on experience at other problem sites, collection and combustion of the gases was considered the most effective way of controlling the odors. The cause of the odor problem was determined to be due to: 1) the disposal of sulfur-laden sludge; and 2) the saturated condition of the landfill cells (i.e., situated in the water table) leading to rapid biodegradation of the wastes.

R&D NEEDS

- Evaluation of the relationship between leachate collection system design and operation in the context of overall site management.

- Evaluations of the impacts of impurities in landfill gas streams (e.g., heavy metals and halogenated compounds) on its potential uses.

- Assemblance of information on models that predict gas generation rates and evaluation of models using results from actual field monitoring.

- Assessment of the applicability of sewer pipeline design, construction and maintenance methods to the leachate collection systems in hazardous waste landfills.

A.4 TECHNICAL DISCUSSION NO. 4

Lockman and Associates: J.Johnson, W. Lockman, R. Lofy

MEESA : M. Ghassemi, K. Crawford

April 23, 1984

Leachate Collection

- The clogging of the leachate collection system (including the sand and gravel filter media) has been a recurring problem at one landfill which Lockman and Associates is very familiar with. This, however, is a very unique site from the standpoint of the type and variety of the wastes handled. The split between "hazardous" and "non-hazardous" wastes at this site is about 33% hazardous to 67% non-hazardous. About 50% by weight of the waste is inorganics and water (the other 50% of the waste is oily organics). The wastes include about 30% liquid wastes and cover a spectrum of industrial wastes. The clogging appears to be due to chemical deposition and solidification. It is very non-systematic in that it occurs only at certain locations while other locations within the same cell perform satisfactorily. The problem thus appears to be related to the variations in the type of waste handled and hence in the leachate characteristics. At this particular site, the corrective measures have included total replacement of sections of the leachate collection system. In general the clogging potential can be minimized or mitigated through proper design to include redundancies in piping, use of suitable sand/gravel gradation for the filter medium, and allowing provision for easy access to the piping system for cleaning.

Gas Mitigation Control

- Considerable gas composition data which have been reported in the literature indicate no substantial differences in the composition of gas from conventional municipal refuse sites and the gas from co-disposal sites which also accept hazardous wastes. In general, the amount of hazardous wastes accepted at co-disposal sites is very small relative to the total waste volume.

- The limited number of landfill emissions studies which have been conducted in recent years indicate that such emissions are primarily related to open disposal activities and improper waste handling.

- Emissions from landfills can be effectively controlled via appropriate waste segregation/handling and through proper design including adequate cover, venting/flare systems, and active gas controls. Banning highly volatile wastes from landfills can reduce potential for emission of volatiles. Some industrial wastes contain significant amounts of volatiles which can even be reclaimed for reuse.

- Although a soil cover of three feet, which is required per regulations, may not be adequate to control emissions, increasing the depth of the soil cover would increase the gas pressure and hence the potential for lateral migration and venting through cracks and discontinuities. Depending on the availability of cover soil, the cost of placing a very thick soil cover (e.g. up to 6 feet) may be less than that of using flexible membrane liners (at least in the Southern California area). Soil cover generally acts as an adsorption system, and unless there is active biological activity in soil, its adsorption capacity will be eventually exhausted. Presence of organics and biological seeds in the soil can promote establishment of a biological "filter" which will effect actual removal of the gas constituents. The Los Angeles County Sanitation Districts have reportedly experimented with the use of sewage sludge in the soil cover or as a refuse cover underneath the soil cover to promote biological activity for emission control.

- Where landfill gases are flared, effective destruction of organics are achieved due to the high temperature and the modern flare designs. The concentration of troublesome combustion products (e.g., HCl) is very small and of no significance to the flare system or the environment. Actual measurements of emissions from these flares in the Los Angeles area has indicated compliance with the very strict requirements of the Air Quality Management District (AQMD).

- Considerable material compatibility problems have been experienced at a number of sites with active control systems for gas recovery. Extensive corrosion of the equipment at one site resulted in the use of a glycol gas pre-cleaning system to remove condensate (and C02). In one application the problem was mitigated by keeping the gas hot to prevent condensate formation.

- At least in the dry climates such as in the Southern California area, underground fires in the landfills are a rule rather than an exception. The heat from such fires can increase volatilization and hence the potential for emission of hazardous air pollutants. The fire and heat have been shown to cause collapse of the gas collection pipes and perhaps can also be detrimental to the leachate collection system pipes and plastic material used as cover or bottom liners. The gas and leachate collection systems, which can act as conduits to provide air, can actually promote underground fires.

- Although there has been some consideration to using horizontal trenches for gas recovery (instead of vertical wells), such systems would be subject to damage due to subsidence and waste/equipment load. The advantage claimed for the horizontal gas collection trench system, which would be installed at various layers as the filling proceeds, is that the gas recovery operation does not have to await completion of the filling operation. Los Angeles County Sanitation Districts reportedly have experimented with the horizontal gas collection system.

R&D Needs

- Parametric evaluation, in full scale "real world" facilities, of various cover systems from the standpoint of emissions control effectiveness. Parameters to be evaluated can include soil type, density, organic content, moisture level, etc.

- Assessment of various configurations for gas/leachate collection systems including some novel designs which would facilitate system maintenance. It is very conceivable that a single system can be provided for simultaneous collection of both gas and the leachate. Design engineers should be more willing to investigate new design approaches and environmental/regulatory agencies should actively promote investigation of novel designs.

- Investigation of differences in geographic and local conditions which necessitate differences in site design and flexibility in regulatory requirements. For example, the landfills in Southern California are largely canyons that have been or are being filled and the very steep canyon walls defy any regulatory requirement for placing/maintaining cover on the liners.

A.5 TECHNICAL DISCUSSION NO. 5

Maryland Dept. of Health and Mental Hygiene: R. Beyer, W. Bonta
L. Martino, R. Rosnick

MEESA: M. Haro

24 April 1984

Leachate Collection

- The state has no direct experience with the leachate collection systems which have been engineered in the original design of hazardous waste landfills. Some experience, however, is available on retrofitting older sites with leachate collection systems, somewhat as a reparative and remedial action measure.

- At two older hazardous waste landfills in Maryland, the completed cells have been retrofitted with leachate collection systems, in order to facilitate leachate collection and removal. At one site, a number of deep (40 to 80 ft) standpipe wells were drilled at the low points in the large cells and were subsequently backfilled with drain rock. Leachate drainage is by gravity flow through the waste to the sumps. The drain rock in the standpipes is slowly filling with fines and will eventually clog the system. Due to the large size of these particular cells, trench excavation for placement of leachate drainage lines was not considered feasible and construction of addtional standpipes was considered cost prohibitive. Thus, this case shows from a corrective measures standpoint that retrofitting a collection system, once the original system fails, is not practical especially for landfills with large cells. At the other site, old chrome ore tailings cells were retrofitted with leachate collection systems for leachate removal and reuse by the generator. Initially, the owner attempted horizontal drilling into the cells. This method proved unsuccessful because of difficulties and delays in drilling through the sandy tailings which tend to cement together over time. Leachate collection lines were finally installed by open cut trenching and laying of PVC pipe every 100 feet and backfilling with drain rock. As far as can be determined, this collection system has performed adequately for a number of years.

- Not all hazardous landfills can be safely retrofitted with leachate removal systems, due to the potential risks and safety problems associated with drilling and excavation in such landfills. At the particular facility cited above, the owner was able to install retrofits because of the certainty regarding the nature and the inertness of the waste.

Waste Handling

- In general, the potential for problems stemming from waste incompatibilty is greater at commercial sites than at on-site facilities, because of the greater variety of wastes received at commercial sites and the lack of detail familiarity of the site operator with the characteristics of the various wastes received.

- In reviewing TSDF permit applications, the permit review team relies on the waste compatibility guide in 40 CFR 264 to identify possible waste incompatibility problems. At the recently closed commercial disposal site, waste incompatibility problems usually occurred during placement of the waste if the generator failed to properly identify the nature of his waste before shipping it to the site.

- To reduce the possiblity of transporting waste off-site, the state requires a truck wash facility at all commercial TSDFs.

Gas Management

- Gaseous emissions from TSDFs are not a significant problem in Maryland primarily because most of the volatile organic wastes generated in the state are shipped out of state for disposal or are recyled. The Air Programs Branch depends on inspectors from other departments (e.g., RCRA inspectors) and the public to notify them of any odor or toxic vapor problems at a particular site. Few odor/gas complaints are received primarily because most TSDFs are located away from residential areas.

A.6 TECHNICAL DISCUSSION NO. 6

Maryland Environmental Service: David R. Foster

MEESA: Michael Haro

25 April 1984

Background

Maryland Environmental Service (MES) is a nonprofit public corporation that operates a number of state and public waste treatment facilities in Maryland. One such facility is the Hawkins Point Hazardous Waste Landfill in Baltimore. The site was originally started under Maryland Port Authority (MPA). In 1975, MPA put chrome tailings in a section of the site. (Previously the chrome tailings were used as a fill material in the Baltimore area.) MES has developed plans and detail designs for expanding the operation at the site and has applied for a permit to carry out the proposed expansion. This technical discussion reviews the background and the design philosophy for site expansion with special emphasis on areas of interest to this project.

Figure 13 is the map of the Hawkins Point Landfill, showing six areas which the site would be divided into under the ultimate site development plan. Under this plan, "Area 3" will provide for containment of general hazardous waste whereas "Area 5" will be used for disposal of chrome tailings waste. Chrome tailings wastes have been previously disposed of in both of these areas. In Area 5, three below grade cells were also filled with chrome tailings. These cells and the disposal site in Area 3 represented the existing landfill under RCRA Part A Interim Status. Because of limited availability of land, the proposed expansion plans call for expanding Areas 3 and 5 in the vertical direction by building up vertical lifts/cells above grade.

The first above ground cell ("Cell 40") is already in place in Area 3. It has an HDPE-clay composite liner and a leachate collection system. Additional cells to be constructed on top of Cell 40 will be lined on the interior side slopes with HDPE-clay composite liner. These cells will not have individual leachate collection systems and their leachates will be removed via the collection system for the bottom cell (i.e., Cell 40). Three above ground cells have already been constructed in Area 5. These bottom cells do not have a composite liner or a leachate collection system similar to those for Area 3 and are only lined on the sides with HDPE. The older (bottom/below ground) cells in both Areas 3 and 5 have been retrofitted with leachate collection systems which discharge to separate collection header pipes.

Basis for Liner Selection

- Cells of the Part A landfill expansion were originally designed with a clay liner only; however, after RCRA land disposal regulations were published in July, 1982, the design was changed to include an FML as a part of the liner system (this was not an immediate technical requirement but it provided an example for private industry to follow). A clay-FML liner system was considered superior to either clay or FML alone, as such a composite system would compensate for the shortcomings of the individual liner type and would take advantage of the desireable characteristics of both systems. Of particular concern here was the

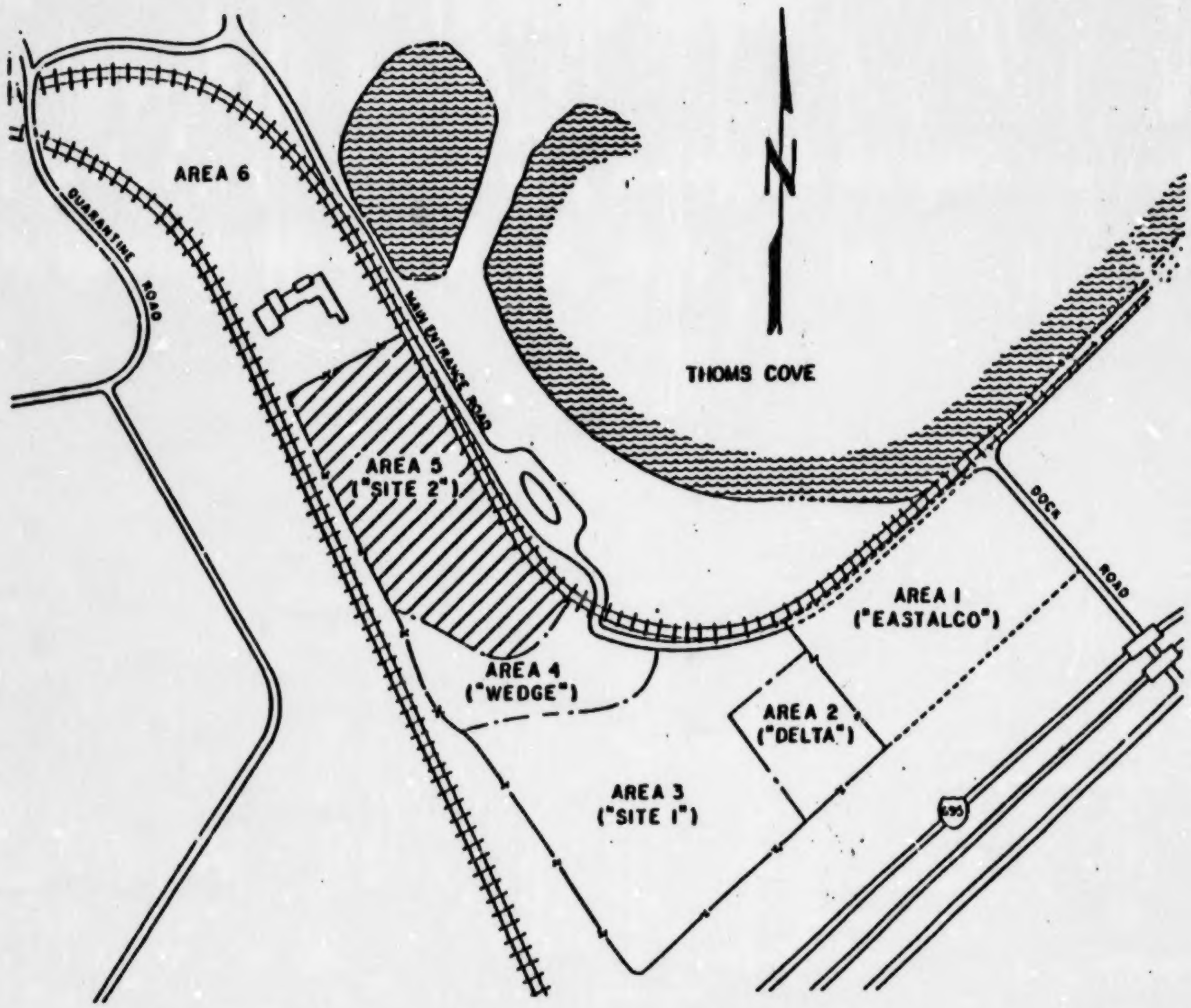

N
THOMS COVE
AREA 6
QUARANTINE ROAD
MAIN ENTRANCE ROAD
AREA 5
("SITE 2")
AREA 4
("WEDGE")
AREA 3
("SITE 1")
AREA 2
("DELTA")
AREA 1
("EASTALCO")
DOCK ROAD
695

Figure 13. Area location map for Hawkins Point Landfill

reported literature data which indicated adverse impact of certain chemicals on clay permeability and the difficulties in installing a leak-proof FML.

- The selection of an 80-mil high density polyethylene (HDPE) liner for the expansion cells was based upon the following: 1) the reported satisfactory operational experience with this material at other hazardous waste landfills in the Northeast; 2) the versatile, inert, puncture resistant and elongation properties of this particular FML; and 3) the state's role in setting high standards for industry in Maryland.
- Having the best possible containment system, and not necessarily the cost, was the primary criterion for liner selection. Thus, an 80-mil thick HDPE was selected over a less costly 40-mil version due to its superior puncture and tear resistance.

Waste-Liner Compatibility

- Because of schedule constraints (and the cost factor), no independent studies were conducted to select the liner most compatible with the expected waste streams at Hawkins Point. The liner-waste compatibility evaluations were based on actual reported operational experience (both good and bad) with various liner types.
- For the Area 3 expansion cell (the general hazardous waste cell 40), a major problem in evaluating compatibility was not knowing the types of wastes that might be disposed of there. Thus, the use of a synthetic leachate (as requested by EPA) for testing with the HDPE was not possible.

Problems During Construction

- The greatest problem during construction was the weather. The installation was scheduled for winter because of time constraints. Earth-work was completely halted during and after rain and snow and liner seaming was not done during high wind conditions.

Retrofitting A Leachate Collection System

- Disposal of chrome wastes in Area 3 began in 1975; it had been then assumed that Area 3 had a continuous clay lining and would provide for adequate containment. However, it is now known that the clay under this site is discontinuous.
- Because borings indicated a 5 to 10 ft leachate head in the old tailings cells (Area 3), the state ordered MPA to dewa-

ter the cells; thus, retrofitting a leachate collection system into these cells became necessary. The construction cost for retrofitting the approximately 16-acre area was $500,000.

- Each leachate collection system consists of a single PVC pipe header and lateral collection pipes. The laterals are 6-inch diameter perforated PVC pipe placed at the bottom of 3 ft wide trenches which were excavated to the bottom of the cell. The bottom 3 ft of each trench was then filled with crushed stone which was encased with Mirafi 140 geotextile. Chrome tailings waste was then placed on top of the geotextile to fill up the trench. There are 3 trenches containing laterals in Area 5 and 14 trenches in Area 3. The trenches in Area 3 vary in length from 160 to 260 ft; the three trenches in Area 5 are approximately 80, 155, and 200 ft in length. The collected leachate flows by gravity to a sump; sump pumps transfer the leachate to storage tanks.

- Problems during construction of these systems included: 1) trenching through cemented tailings in several areas; and 2) exposure of excavated tailings to rain.

- Manholes were provided outside of the cells on the main collection header at all bends and junctions, and at spacing not greater than 400 ft. This allows closed circuit television monitoring of the condition of the pipe, cleaning, and to a limited extent, physical repairs to be made to the collector without excavation.

- Headers and sumps were located outside the containment areas because of the proposed vertical expansions. Although leachate collection systems located totally within the cell may provide better containment (i.e., no appurtenances crossing the liners), stacking 2 or 3 cells vertically would require very tall manhole towers which might cause greater potential damage to an FML.

Miscellaneous

- Provided that the bottom cells are provided with a reliable liner system, vertical expansion of a landfill (i.e., new cells placed on top of starter cells) would perhaps be more cost-effective than expanding the landfill outward. In general, however, above ground landfilling is much more expensive than excavation landfilling.

- At least a one-ft layer of soil should be placed over FML sections during installation at the end of each work day ; otherwise, the liner will billow and tear during windy periods. Seaming should begin on the uphill end of the cell to avoid collection of rainwater under the liner.

- A concrete unloading ramp (for bulk wastes) located in the cell can save valuable disposal space and affords protection for the bottom liner. A front end loader operating on a concrete pad can pick up bulk wastes without fear of excavating too deeply into the cell bottom. The pad also eliminates the need for replenishing soil in the pickup area.

- EPA's one-ft leachate head requirement may not be a practically achievable standard; it would require crushed stone or gravel to provide adequate permeability which might threaten the integrity of the liner. Furthermore, there would be a substantial additional cost for placing laterals very close together if the drainage layer was composed of sand.

- In areas where differential settlement may be expected, the use of a flexible plastic collection pipe (lateral) may have an advantage over rigid pipe. Even if the pipe partially closes due to overhead stresses, leachate will still be collected, whereas a broken rigid pipe may stop the flow.

A.7 TECHNICAL DISCUSSION NO. 7

Duffield Associates, Inc.: Jeffery M. Bross, Glenn K. Elliot

MEESA: Michael Haro

April 26, 1984

Leachate Collection

- All landfills will generate leachate at some point even in the arid Southwest; hence, prudent attention to leachate collection system design for hazardous waste landfills is a necessity. In general, the experience of the design engineer with actual landfill operation and his familiarity with the complexities involved is prerequisite for developing a good leachate collection system design. Such a design would feature the following:

  -use of very resistant pipe material based on the anticipated leachate characteristics;
  -use of copious quantities of large diameter drain rock (preferably quartz- or silica- based stone);
  -use of large diameter perforated pipe;
  -spacing of drainage laterals 200 to 300 ft apart;
  -responsiveness to site-specific factors such as waste properties, hydrology, etc.

- Based on actual experience with engineered landfill sites featuring leachate collection systems, it is imperative that large diameter rock, preferably crushed stone,(minimum size of 1-1/2 in.) be used in drainage collectors to provide a hydraulic backup layer in case leachate collection pipes should clog. Based on experience with leachate collection pipes that have filled with migrating fines and anaerobic scum, the larger the drainage aggregate, the longer and more effectively the drainage system will perform. The aggregate should be placed against the waste so that even when fines from the waste enter the system, the large rock provides adequate porosity to maintain leachate flow. A filter fabric should never be placed between the waste layer and the leachate drainage system as these materials are likely to clog. A geotextile is not a substitute for an aggregate in this situation.

- An example of a leachate collection system designed to prevent lateral migration away from the landfill is provided in Figure 14 . This system incorporates the large drain rock, washed gravel, perforated PVC pipe, and an FML. After eight years of service in a landfill in the Northwest, parts of a leachate collection system, similar in design to that shown in Figure 14, were excavated in order to determine the integrity of the drains. The pipes and drain rock were still very porous and in excellent working order.

- Those landfills which feature sand drainage layers for leachate collection are likely to have problems. Sand is simply too fine a material to be used as a drainage medium for leachate collection applications and certainly would not meet EPA's one foot leachate head requirement. (Realistically, most of even the best designed systems would fail to meet this head requirement. Conceivably, and depending on "sand" gradation, it would require spacing leachate collection laterals no more than 20 feet apart to satisfy the one foot leachate head requirement.)

- The major problem with leachate collection systems is that once the drainage medium becomes clogged, it cannot be cleaned out; therefore, the design must incorporate considerable redundancies (e.g., use of as large an aggregate material for drainage as is feasible).

- Landfill operators should draw upon sewer system technology in developing leachate collection system inspection and maintenance programs. A significant amount of sediments will deposit in leachate collection laterals and mains to require cleaning after the first six months of operation. Thereafter, laterals and mains should be inspected and cleaned every 2 to 3 years. Video monitoring of pipes is a recommended inspection procedure for 6-inch diameter or

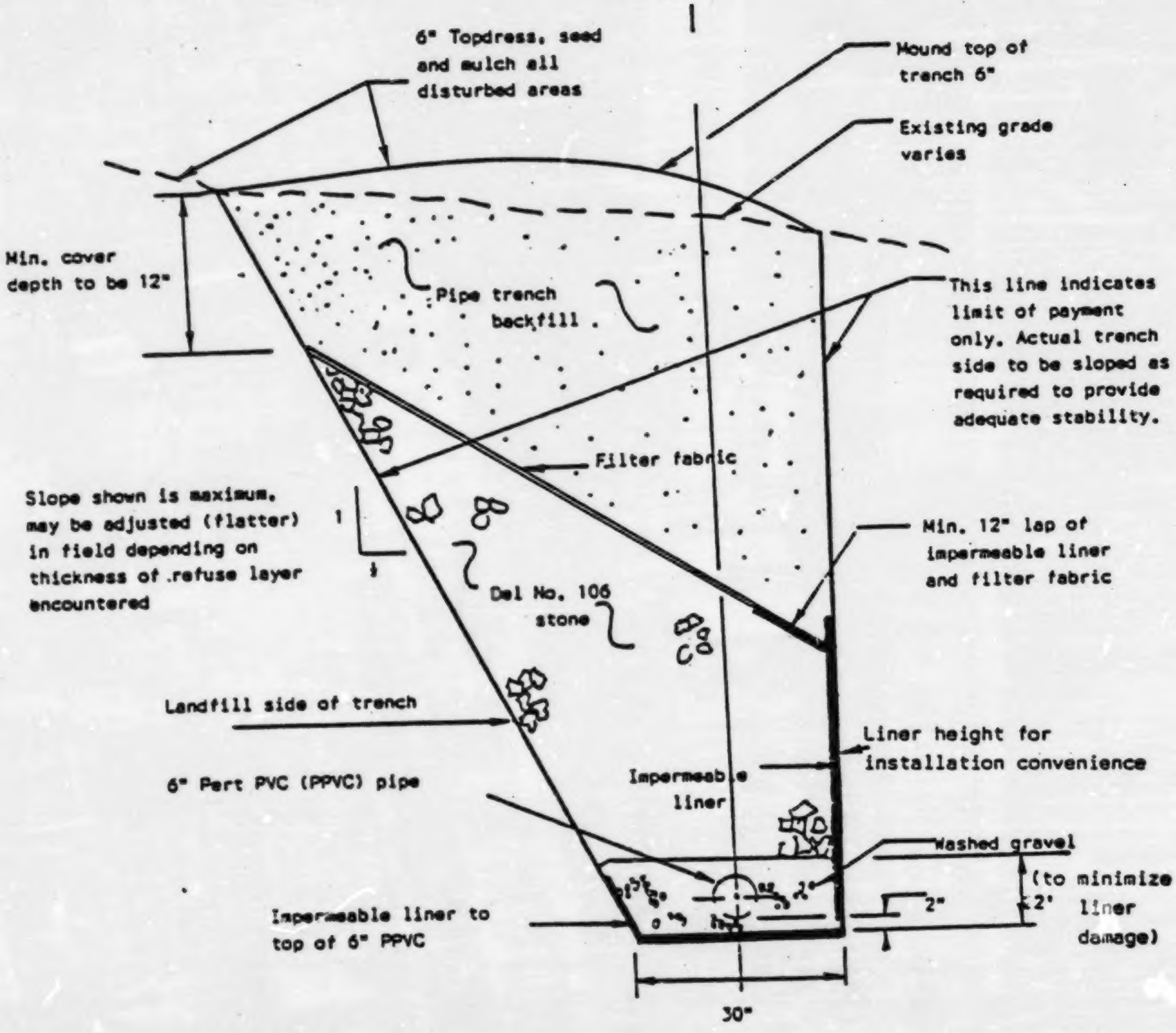

6" Topdress, seed and mulch all disturbed areas
Mound top of trench 6"
Existing grade varies
Min. cover depth to be 12"
Pipe trench backfill
This line indicates limit of payment only. Actual trench side to be sloped as required to provide adequate stability.
Filter fabric
Slope shown is maximum, may be adjusted (flatter) in field depending on thickness of refuse layer encountered
1
½
Min. 12" lap of impermeable liner and filter fabric
Del No. 106 stone
Landfill side of trench
Liner height for installation convenience
6" Perf PVC (PPVC) pipe
Impermeable liner
Washed gravel
2"
(to minimize liner damage)
2'
2"
Impermeable liner to top of 6" PPVC
30"

Figure 14. Leachate collection trench (not to scale)

greater pipe (the required equipment will not fit in smaller sized pipe). The pipes can be cleaned with rotorooters or hydroblasting. Rotorooting is not recommended for perforated PVC because of potential damage; sewer jet is recommended for this type of pipe. Hydroblasting with sewer jets is very effective and also cleans out pipe perforations but is only effective for a certain length of pipe. Depending on equipment capability, the maximum length of pipe that can be cleaned is 500 to 700 feet for both methods. Therefore, manholes and cleanouts should be sited based on these limitations. An examples of a cleanout station is shown in Figure 15. Sewer maintenance contractors are located in most large cities and typically charge about $1000 per day for video inspection and cleaning (which is equivalent to approximately 900 feet of pipe).

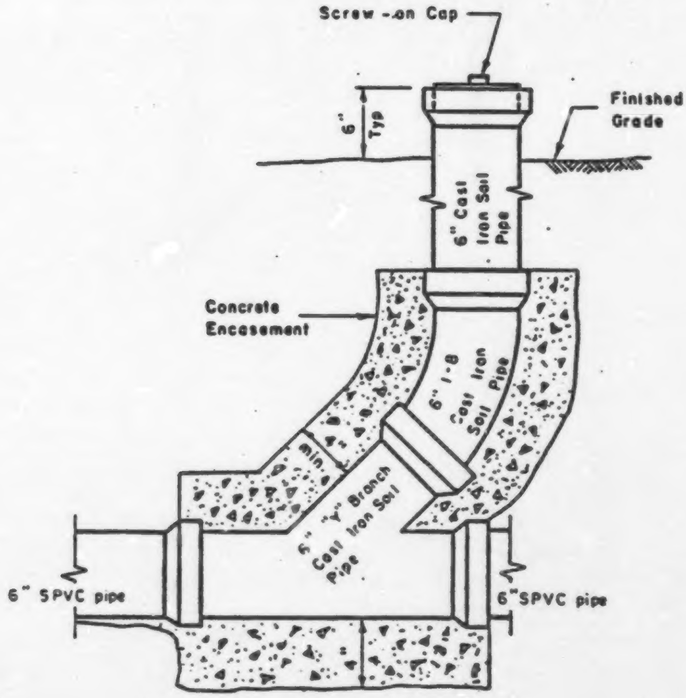

Screw -on Cap
6" Typ
Finished Grade
6" Cast Iron Soil Pipe
Concrete Encasement
6" 1-8 Cast Iron Soil Pipe
4" min.
6" "Y" Branch Cast Iron Soil Pipe
6" SPVC pipe
6"SPVC pipe
4"

Figure 15. Sewer Cleanout

A.8 TECHNICAL DISCUSSION NO. 8

Residuals Management Technology, Inc. (RMT): John J. Reinhardt

MEESA: M. Ghassemi, K. Crawford

April 30, 1984

Leachate Collection

- Actual experience with engineered sites featuring leachate collection systems is very limited. In Wisconsin, for example, first generation engineered sites went into service about mid 1970's and it was not until about 1980 when some operating data became available for these sites. As with all engineered systems, and despite the use of best engineering judgment in design, there will undoubtably be some failures of the leachate collection systems. Information on what designs will or will not work over a very long design life is not currently available and the engineers have to continue to rely on their best engineering judgment in designing such systems. Even though the systems which have been designed by RMT do not have a very long operating record, to date there has been no problem with any of their designs. The oldest operating site with a leachate collection system in Wisconsin is the "Olin Avenue" site which was placed in service in 1970; the leachate collection system at this site is still functioning adequately. Other sites in the state for which about 3-4 years of experience is available are Brown County, Madison, Winnebago County, Outagamie County, and Marathon County sites. A similar length of experience also exists for the Kent County Site in Michigan.

- The current approach to minimizing potential future problems with the leachate collection systems is to incorporate much redundancies in the design. The sketches in Figure 16 illustrate examples of progressively increasing redundancies involving extending the collection laterals and header pipe to outside the fill area (Sketch B) to make them more accessible for maintenance , use of manholes at the connection points (Sketch C), and use of an auxiliary gravel trench to intercept any leachate not drained through the piping system (Sketch D).

- There is currently no uniform approach to leachate collection system design. Although RMT has a generic design approach (philosophy), the design is tailored to a specific case and takes into account the often changing requirements of the permitting agencies. Wisconsin Department of Natural Resources, for example, now requires the use of geotextile to line the interior side walls and the bottom of the gravel

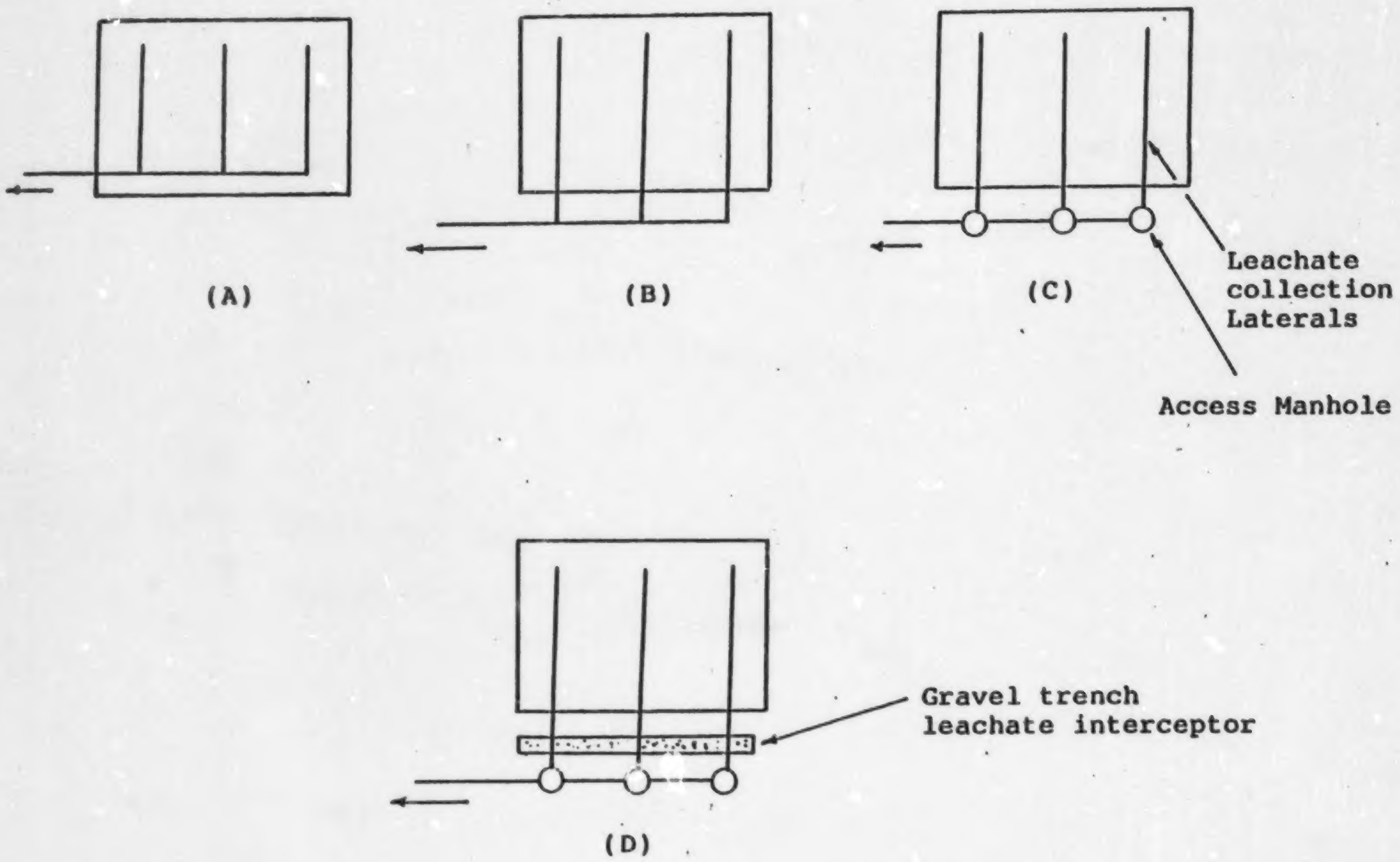

(A)
(B)
(C)
Leachate collection Laterals
Access Manhole
Gravel trench leachate interceptor
(D)

Figure 16. Examples of progressively increasing redundancies for LCS

trench. There are also some differences between "hazardous " and conventional "non-hazardous" waste sites which have to be taken into account in the design; these differences relate to differences in leachate characteristics (e.g., use of limestone-based drainage gravel may not be advisable when the leachate has low pH), waste densities and water content and drainage characteristics of the wastes.

- There is no firm basis/criteria for determining whether a leachate collection system is experiencing clogging. The water budget method of determining leachate flow for design purposes may not be accurate as a basis for determining the extent of clogging. Use of head wells for direct observation of leachate levels is a preferred method and the one which is now required by Wisconsin Department of Natural Resources.

- Periodic (e.g., once-a-year TV) inspection of at least selected lines for clogging is an element of a good maintenance program, although the exact maintenance requirements are dictated by the regulatory agencies. There is no substantial difference between cleaning techniques for sewer lines and for leachate drainage pipes.

- The clogging and service life experience with the agricultural drainage systems would not be applicable to the leachate collection systems because of the differences in design and construction practices and the lack of rigorous QA/QC in the construction of tile drain systems for agricultural drainage.

R&D Needs

- Case studies must be carried out to assess the performance of full-scale leachate collection systems which have been in service for a number of years. In the coming years, it should be possible to obtain somewhat longer-term operating data for a number of sites. In certain instances the evaluation of the performance may necessitate actually digging out part of the collection system for direct observation. Pilot scale lysimeter-type studies using real wastes can also provide some performance data, although the results would not be as reliable. Some sort of plastic is now used as the piping material for the leachate collection systems. Only through long-term field studies can information be obtained on the longevity of these pipes in the harsh (e.g., potentially high temperature) landfill/leachate environment.

A.9 TECHNICAL DISCUSSION NO. 9

Department of Natural Resources
State of Wisconsin: M. Gordon, P. Kmet, G. Mitchell

MEESA: M. Ghassemi, K. Crawford

May 1, 1984

General

- The State of Wisconsin does not have specific regulations for design of clay liners and caps, leachate collection systems and gas venting and recovery devices. The Administrative codes (written in 1971 and revised in 1980) are sufficiently general to allow varying interpretations in connection with the site approval process. This regulatory flexibility is necessary as the technology advances and operating data from previously approved sites/designs become available. The issue of waste handling and placement is also handled primarily as part of the site approval process.

- Currently there are no active hazardous waste disposal sites in the state. At one time there were three co-disposal sites in the state (two operated by Waste Management, Inc.), which mixed hazardous waste with typical municipal and commercial waste. These sites stopped accepting hazardous waste in January 1983 when the new RCRA land disposal regulations came out. These sites are also "grandfathered" sites which have been continuously expanded and to which various features and subsystems have been added over the years. One facility is currently undergoing remedial action to cut off permeable seams with bentonite slurry, clay cut-off walls and leachate collection systems.

- There are about 1200 "licensed" disposal sites in the state, of which about 900 are small (50,000 cu yd) modified dump sites which also fall in the "natural attenuation" site category. A limited number of these small sites have some sort of leachate collection back-up system (e.g., "toe" leachate collection systems). The remaining 300 sites fall into the following categories:

  - -Clay-lined landfills (lined typically with four to five feet of clay) with leachate collection systems. These sites are typically larger (200,000 cu yd) and newer sites (or expansions of the older, existing sites).

  - -"Zone-of-Saturation" landfills, which are constructed in low permeability clay soils below the water table and required to have leachate collection systems and to maintain a low leachate head (1 ft).

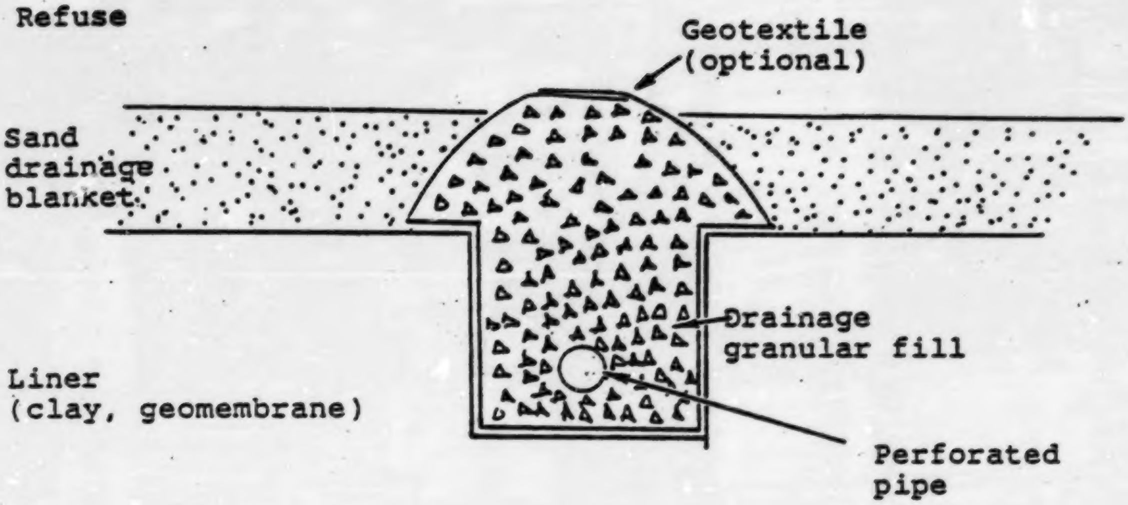
-Remedial action sites (where, for example, cut-off walls and trenches with leachate collection systems have been installed).

- In 1976-77 Wisconsin began to require installation of leachate collection systems and there are now about 50 sites with leachate collection systems.
- There are about 20 landfills handling mostly paper mill wastes.
- There are not very many surface impoundments in Wisconsin; the surface impoundments handle mostly metal plating wastes.
- Although Wisconsin has considerable experience with leachate collection systems, its experience with gas management systems is limited. There are currently less than 10 "active" gas venting systems in use. All new and expanded landfills since 1980 are required to include a passive venting system at a minimum.

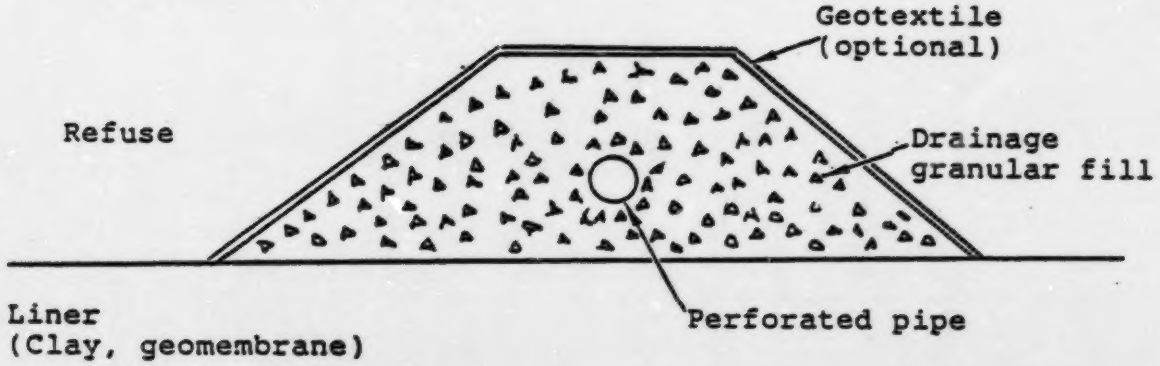
Leachate Collection

Typical Designs and Related DNR Requirements--

- Typical leachate collection designs use 6-inch PVC pipes (4-inch pipes were used in the mid to late 70s but due to ease of cleanout, all new systems require 6-inch pipe), although ABS pipes have also been used in some installations. As a general guideline, "Schedule 40" pipes are required where the waste fill is not expected to be greater than 50 ft; "Schedule 80" pipes are required when the fill depths would exceed 50 feet. Schedule 40 pipes have predrilled perforations whereas the Schedule 80 pipes require drilling at the site. Because of the field drilling requirement, there has been some reluctance to the use of the Schedule 80 pipes when not structurally required.
- In the earlier designs, the leachate collection laterals were typically not buried in trenches (in the form of a "negative" projection) but placed on the landfill bottom and covered with the drainage medium (as "positive" projections) (see Figure 17). Because of some problems due to waste movement, damage of the lines by equipment movement and the potential for washout of the drainage material with the positive projection type design, the negative projection design (A in Figure 17) is now required. The use of a sand layer on the liner and mounding of the gravel over the


Refuse
Geotextile
(optional)
Sand
drainage
blanket
Drainage
granular fill
Liner
(clay, geomembrane)
Perforated
pipe

A. Negative projection mode


Geotextile
(optional)
Refuse
Drainage
granular fill
Liner
(Clay, geomembrane)
Perforated pipe

B. Positive projection mode

Figure 17. Positive and negative projection drain designs

trench (see sketch) is necessary to promote drainage.

- Lining the interior of the drainage trench with geotextiles has been required for most new designs. Geotextiles have been used in this mode of application in about 25 installations in Wisconsin. The lining of the trench is intended to prevent soil particles from the liner to enter the drainage envelope and cause siltation. Some sites have experimented with extending the geotextile to cover the top of, and hence envelope, the gravel trench. This design, however, is somewhat controversial and the long-term effectiveness of geotextiles in providing adequate drainage remains to be seen.

- At some natural clay sites where the side walls have been very steep (nearly vertical at some areas) there have been problems with erosion of the clay material, some of which subsequently found its way into the leachate drainage system. To avoid the potential clogging problem, the state now requires that even the natural clay sites be provided with a side slope of at least 3:1 (H:V) and that a sand layer be placed on the side slope to prevent erosion washing of clay.

- The leachate collection pipes are required to have 500-ft cleanout access (i.e., 1000 ft. maximum pipe length between two cleanouts) and that leachate head wells are to be installed in each major phase of the landfill (at least one at the low end and one halfway up the slope).

- Use of "sweep" bends instead of sharp bends (90^o turns) at pipe connections (to provide better access for cleaning) and construction of the leachate riser pipe in the wall of the landfill (instead of placing it in the fill or on the surface of the sidewall where there may be a potential for damage due to waste load and movement) constitute good design practices.

Operating Practices and Related DNR Requirements

- As part of the requirements for obtaining an operating permit, site owners/operators must demonstrate ability to clean all leachate collection lines. The state also recommends that the lines be flushed after the first lift of waste has been placed. During the site operation, the leachate level in the head wells must be monitored and the leachate flow (i.e., the volume of leachate pumped out) must be recorded and the records (along with the ground water monitoring data and leachate composition analysis) must be submitted to DNR on a quarterly basis.

- DNR currently requires annual cleaning of all leachate collection lines. A report documenting each cleaning effort including identification of the lines cleaned and success or failure of the cleanout is to be submitted to DNR. The report should include photo documentation and should present proposals for reparative measures in the event that a cleaning effort has not been successful. DNR is also to be notified at least two weeks in advance of cleaning date so that a representative can observe the effort.

- The DNR's requirement for annual cleaning of the leachate collection lines has been formally challenged by at least one site owner/operator who feels that monitoring of leachate flow by itself is sufficient to detect problems, and that only after a problem has been detected should cleaning effort be undertaken. The DNR rebuttal to this assertion, however, is that (a) in general, industry has not demonstrated a good record for self-policing, (b) the annual cleaning would be a good preventive measure as it would flush out any accumulation before it becomes too difficult to dislodge, and (c) the cleaning cost is relatively small (depending on the number of lines involved, the line cleaning would require a maximum of only two days' effort).

- Cleaning of leachate collection pipes is carried out by commercial sewer cleaning companies and there are no specific companies specializing in leachate collection pipe cleaning service.

- Use of half or whole corrugated pipes to cover trenches where there is trafficking has been required by DNR. This requirement, however, has only been partially effective as traffic path constantly changes as the operation proceeds. Therefore, sites are designed to eliminate traffic on the liner and over the collection pipes.

- Leachate perching and seepage due to inadequate drainage through the waste has been a problem at one Wisconsin landfill which has received significant percentages of shredded refuse and paper mill sludge and which has used on-site clay soil for daily, intermediate and final cover. The low permeability of clay soil and shredded refuse acted as barriers to leachate (and gas) movement. It is also believed that since the leachate collection system drainage envelope consisted only of gravel with no sand layer filter media on top of gravel, the fine particles in the paper mill sludge penetrated and clogged the gravel layer. (Based on the information provided in the reference cited below, over half of the refuse received by Phase I was shredded and more than 200,000 tons of the in-place waste is paper mill sludge Reference: Stecker, P.P. and Garvin, J.W., "Control and Prevention of Landfill Leachate Seeps", Proc. 6th Annual Madison Conference of Applied Research and Practice on Municipal and Industrial Waste, Sept. 14-15, 1983, Dept. of Engineering and Applied Science, Univ. of Wisconsin.)

- To avoid drainage problems similar to that experienced at this site, DNR now advises against the use of clay or other low permeability material as daily cover and recommends the use of sand as cover material at least for the first lift and scarification of clay cover in the upper lift prior to placing new refuse. (In the past, landfill operators have generally used as daily cover whatever material was available onsite or nearby).

- The placement of low permeability wastes (e.g., shredded refuse) over large continuous areas is considered a poor practice and should be avoided. Low permeability wastes should be blended with refuse as much as possible or placed in smaller isolated areas which are not interconnected. Wastes containing fine particles and leachable materials (paper mill sludge, ash and foundry waste) should be placed near the top and definitely not in the first lift.

- Leachate entrapment due to poor drainage has also been a major problem at another site. Based on leachate levels measured in the various head wells, perched leachate levels exist at this site. The mounding of the leachate has been attributed to the clayey nature of the cover material used. As each daily refuse cell was encapsulated with cover, it was effectively sealed and downward leachate migration was restricted. The operating practice has since been modified at the site and the operator now strips the previous day's cover in the active filling areas to promote downward migration of leachate.

Gas Control

- DNR requires passive gas management (venting) at all post-1980 sites, with the additional requirement that the system can be readily converted to active system if necessary.

- Only at one site in Wisconsin is gas recovered as an energy source (at this site, the recovered gas is used to heat on-site buildings).

- Underground fires have not been a problem at Wisconsin landfills due to the wet climate and the strict regulations and inspection which would prevent disposal of hot ashes and flammable wastes.

- Type of waste handled and waste placement practices can have a significant impact on gas migration potential. At the landfill reviewed above, exceptionally high gas pressures have been documented.* The presence of high proportion of pulp mill sludge and shredded refuse in the fill and the use of clayey soil as daily and intermediate cover are believed to be responsible for the gas pressure buildup. At another site, where only shredded refuse was handled without any daily cover, pressure buildup resulted in lateral gas migration and an explosion at a nearby structure. An active gas control system was in place along one edge of the landfill, but because of the compact nature of the waste the system was apparently ineffective in collecting the gas from the entire site. Corrective measures, which were subsequently implemented, involved extension of the gas suction system around the entire perimeter. The collected gas is flared at this site.

- Emissions from landfills and surface impoundments have not been an issue in Wisconsin, as most sites are located in isolated areas. At one or two bigger sites, DNR has required emission monitoring, mainly for particulates. Odor problems have been dealt with by venting and flaring landfill gas or placement of bark waste over paper mill sludge waste.

R&D Needs

- Assessment of the use and the long-term performance of geotextiles in the landfill environment, including criteria for selection of suitable geotextiles and potential for formation of and growth of biological flocs on the matrix.

- Evaluation of the attenuation capacity of clay liners for leachates generated in municipal landfills. The leachate from some of these sites can be significantly more troublesome due to variability than those from the so-called hazardous waste sites. Use of lysimeters (small collection basins directly beneath the clay liner) such as those now required by DNR for new sites can provide the answer to the question of how much of what leachate components does actually go through the liner. (DNR now requires the use of lysimeters under most clay-lined sites to check the permeability of the liner and to evaluate its attenuation capacity for the portion of leachate not collected in the leachate system. This requirement, however, has been challenged on the ground that it constitutes an R & D effort and should not be a design requirement for operating sites.)

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* Typical landfill gas pressure ranges from tenths of an inch up to two inches of water column. However, gas pressure measurements at this site indicated pressures of several inches of water column or more at most locations, 20 inches or more at many locations, and greater than 150 inches at some locations (Stecker, P.P. and Garvin, J.W., "Control and Prevention of Landfill Leachate Seeps", Proc. 6th Annual Conference of Applied Research and Practice on Municipal and Industrial Waste, Sept 14-15, 1983, Dept. of Engineering and Applied Science, University of Wisconsin, Madison, WI.)

A.10 TECHNICAL DISCUSSION NO. 10

Warzyn Engineering, Inc.: R. Cooley, D. Kolberg, D. Viste

MEESA: M. Ghassemi, K. Crawford

May 2, 1984

Leachate Collection

- Even though extensive operating experience is not yet available, clogging of leachate collection systems is not expected to be a potential problem because of the considerable redundancies which are incorporated in the design of such systems. These redundancies include (a) use of collection pipes which are significantly oversized for the flows which they are to carry, (b) relatively close spacing of the collection trenches (i.e., a large number of laterals) which would allow for the leachate to flow through alternate paths in the event that specific line(s) fail and (c) the significant hydraulic capacity of the gravel trench itself to convey fluid. In addition, providing cleanouts and following an inspection program affords an opportunity to remove debris that does accumulate. This assessment is supported by the experiences from at least two major sites in Wisconsin where inspection of a section of the leachate collection system indicated no evidence of clogging or deterioration after some 10 years of actual service. Except for some discoloration, the gravel in the trench was very clean and appeared intact.

- It is inappropriate to draw conclusions as to the expected performance and service life of the leachate collection systems based on experience with the agricultural drainage systems, because of the differences in design, construction and maintenance practices for the two systems. For example, tile pipes used in agricultural drainage systems are constructed with open joints, the construction effort receives little or no QA/QC and there is no subsequent maintenance (cleaning) and repair program for these systems.

- Getting the leachate to drain through the refuse and reach the leachate collection underdrain presents a much greater design and operation challenge than getting the leachate to exit through the underdrain once it reaches the underdrain. Use of appropriate material for the daily cover and implementation of proper waste handling and emplacement practices are critical in promoting leachate flow through the waste.

- At one major Wisconsin site, the mounding of leachate and the existence of perched leachate levels have been attributed to the clayey nature of the soil used for daily cover. As each daily refuse cell was encapsulated with cover, it effectively sealed the waste and downward leachate migration was restricted. Reparative measures which have been considered and/or are being undertaken at this site to promote leachate flow and removal include drilling caissons to various depths within the fill and constructing a gravel "trench" all the way to the bottom of the fill along the inside periphery of the site. These reparative measures are very costly (considering a fill depth of up to 200 ft) and may not have been needed if a more permeable material had been used for the daily cover. At the present time the operation at this site has been modified so that a previous day's cover in the active filling areas is stripped to promote downward leachate migration. Experience at other sites has indicated that shredding of the refuse prior to placement in the fill (to conserve space and eliminate need a for daily cover) can also result in a decrease in waste permeability, and hence leachate perching.

Gas Migration Control

- Warzyn considers "active" systems for gas migration control more effective, environmentally safer, and publicly more acceptable than the "passive" systems. They have used active systems in some designs. Gas control systems may emit potentially hazardous materials to air and constitute a safety hazard, especially in areas where there is a likelihood for trespassing. There has been some consideration for constructing taller vents to promote dispersion and/or posting warning signs near these potential emission sources. The public also generally "feels" more comfortable ("safer") with the active systems as it sees or hears the blowers in operation.

- As with the leachate management system, the effectiveness and cost of active gas control systems are impacted by the type of waste handled and the operating practices. Shredding of refuse can result in a dense waste which can impede gas movement. Leachate recirculation, seeding of the daily cover and use of permeable material for daily cover can enhance gas production and recovery. Provided that the landfills are specifically designed and operated for gas recovery, they can perhaps prove to be desirable and cost effective resource recovery systems, if these considerations are targeted early as major objectives.

- Air quality monitoring around landfills is perhaps in an evolutionary stage now and there are currently no protocols nor guidelines for such monitoring. In the past emission of particulates (dust) has been the primary concern. A limited ambient air monitoring effort is currently underway at several Wisconsin sites. Perhaps a matter of greater concern at operating sites is workers' safety in connection with waste placement and reparative measures projects.

R&D Needs

- Parametric studies should be conducted at full scale sites to relate design, construction and operating factors to performance. Factors that could be studied include waste stabilization, resource recovery, environmental safety and long-term cost impacts. Many of the parametric studies in the past have utilized small scale units which do not adequately represent operating practices and conditions in full scale landfills (e.g. use of daily covers). Large scale studies can best be carried out at these facilities for which substantial background data (e.g., runoff, precipitation, leachate volume, etc.) already exist. The background data should be used to first "calibrate" the models which have been proposed to estimate leachate quantities and percolation rates. Evaluation of factors affecting leachate and gas generation, quality and flow should then follow. Factors to be varied in such an evaluation can include leachate recycling rates, the extent of seeding of cover layers, and waste properties.

- Investigation of how the refuse mass behaves in the landfill environment from the standpoint of permeability to gas and leachate. For example, it is not currently known what size particles result from waste degradation and their potential for deposition in the leachate collection system.

- Evaluation of various approaches to retrofitting older sites with leachate collection systems (i.e., what are the cost-effective methods for extracting/intercepting the leachate from these older sites), when such systems were not originally incorporated into the design, or when original systems are shown to be ineffective.

- Verification of the applicability of the standard civil engineering design curves and equations for pipe sizing to the unique conditions of the leachate collection systems. For example, estimation of pipe deflection as a basis for sizing currently uses equations which have not been specifically developed for small pipes in relatively narrow trenches and subjected to often high waste loads. Some extrapolation from standard curves/equations is often made and the accuracy of the standard curves and equations at these very "low ends of the scale" remains to be verified.

- Evaluation/promotion of design innovations (perhaps through government financial support for such projects). One innovation in design which can perhaps revolutionize the entire approach to waste disposal would be to view landfills not as waste containment cells and repositories of indefinite and uncertain life requiring long-term care, but as reaction vessels and resource recovery centers with a finite service life. Active degradation of waste and gas generation would be intentionally promoted and the design and operation would be aimed at achieving these objectives. The ability to predict service life would enable engineers to design their systems for an estimated life. This would eliminate the current uncertainties as to the long-term performance of the system components (e.g., liner, leachate collection system, etc.) and the transfer of potential problems to future generations.

  One design innovation which specifically relates to the leachate collection system, and one which has been given some serious consideration at Warzyn, involves provisions to allow draining of the entire leachate collection trench, and not merely the embedded pipe. The gravel trench is capable of carrying a significant volume of flow, especially in deeper landfills for which the gravel trench would be deep and the pipe cross section would only be a small fraction of the total drainage cross section.

- Development of background information and assessment of pollution problems associated with existing municipal solid waste disposal sites. Considering the large amounts of hazardous wastes which have been previously deposited at these sites, and the wastes from numerous small volume hazardous waste generators which continue to be deposited at these sites, the environmental impacts for these sites (many of which have little or no engineering design) can be far greater than those from properly designed dedicated hazardous waste sites.

- Development of approaches for achieving greater uniformity among regulatory requirements of states with similar environmental settings. One approach worthy of consideration is Federal review of state regulations and enforcement policies. Promotion of exchange of information and experience among states located in regions with similar conditions and characteristics would also be helpful in promoting more uniform regulatory interpretation and enforcement policies.

A.11 TECHNICAL DISCUSSION NO. 11

Black & Veatch : J. David, Jr.; R. Koltuniak

MEESA: M. Ghassemi

May 22, 1984

Leachate Collection

- Conventional filter design techniques commonly used in construction and agricultural applications were utilized in the design of leachate collection systems for the Virginia Beach, Virginia, Sanitary Landfill No. 2 and the Maryland Environmental Service, Hawkins Point Landfill.

- The drainage layer, as designed, consists of 12 inches of select drainage materials, similar to American Association of State Highway and Transportation Officials (AASHTO) M43, size no. 8, with an average hydraulic conductivity of 1.0 x 10^{-2} cm/sec. To prevent clogging of the drainage layer, a non-woven filter fabric similar to Mirafi 140N is installed above the drainage layer. This fabric will prevent fine particles from clogging the drainage media. To protect the filter fabric from possible equipment traffic and deterioration, a 12-inch layer of coarse aggregate, similar to AASHTO M43, size no. 57, is placed over the filter fabric. To prevent clogging of the leachate collecting piping, a coarse aggregate bedding material will envelope the pipe. The bedding material is entirely surrounded by a non-woven filter fabric (see Figure 18). This should effectively eliminate fine particles from entering the coarse aggregate and clogging the perforated pipe. The coarse aggregate surrounding the pipe should meet the requirements of AASHTO M43, size no. 57. The minimum particle size will be 4.75 millimeters (mm), and limited to 5 percent by weight of the material. Perforations of standard 6-inch diameter polyethylene piping are approximately 2.0 mm; therefore none of the coarse bedding should enter the pipe, and clogging should not occur.

- In the unlikely event clogging does occur, and in order to allow for periodic inspection, the system has been designed to be accessible from a series of manholes. Manholes are provided outside of the cells in the main collection header at all bends and junctions, and at a spacing not greater than 400 feet. This will allow closed-circuit television monitoring of the condition of the pipe, cleaning, and, to a limited extent, physical repairs to be made to the collector

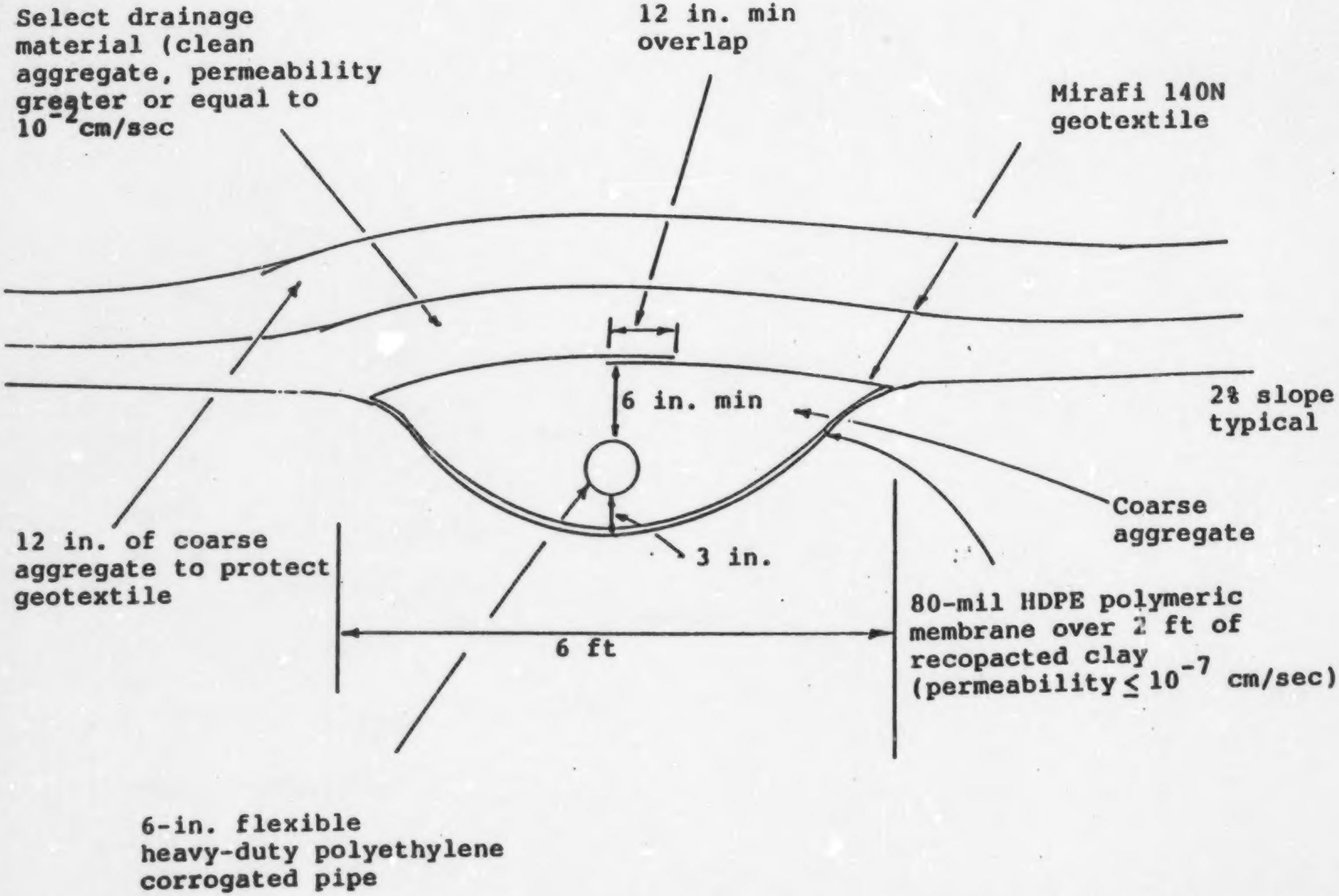
Select drainage
material (clean
aggregate, permeability
greater or equal to
10^{-2} cm/sec
12 in. min
overlap
Mirafi 140N
geotextile
6 in. min
2% slope
typical
Coarse
aggregate
12 in. of coarse
aggregate to protect
geotextile
3 in.
6 ft
80-mil HDPE polymeric
membrane over 2 ft of
recopacted clay
(permeability $\leq 10^{-7}$ cm/sec)
6-in. flexible
heavy-duty polyethylene
corrogated pipe

Figure 18. Cross section of LCS for the proposed expansion to Hawkins Point landfill

without excavating. It will also enable leachate samples to be obtained at various locations in the collection system.

- In general, there is limited experience with the performance of leachate collection systems used in full-scale facilities (about 2 years for systems designed by Black & Veatch.)

- The potential for clogging of the leachate drainage systems would be expected to be partially dependent on the type of the leachate to be handled, and extensive information generally does not exist on the characteristics of the leachate. This problem is especially difficult to address when the facility is to receive a wide range of wastes containing numerous individual compounds (or classes of compounds), thereby yielding a leachate which would be very complex and variable in characteristics. The problem of predicting leachate characteristics is perhaps more manageable when the facility is compartmentalized and operated as separate cells (approaching a monofill-type operation).

- When leachate of varying characteristics are to be handled at a site (e.g., leachate from separate cells handling different waste types or from old and new cells), the design of any combined leachate conveyance system should take into account the possibility of precipitate formation and deposition due to mixing of possibly incompatible leachates.

- A cross sectional sketch of the leachate drainage system for the proposed expansion to the Hawkins Point hazardous waste site is shown in Figure 18. Except for the elimination of the coarse aggregate layer on top of the select drainage material (sand), this same design has been used for the expansion of the Virginia Beach landfill. Recognizing the lack of experience with the use of filter fabrics in leachate collection system, the selection of the particular geotextile to promote drainage was based on reported experience with the non-woven fabric filter in drainage systems. The preference for heavy duty polyethylene (HDPE) pipe for leachate collection over PVC resulted from cost, chemical compatibility and engineering considerations (e.g., ease of installation, crushing strength and wall buckling) and some cracking of rigid PVC pipes reportedly experienced with the use of such pipes in gas collection systems (attributed to the subsidence problems).

Gas Collection

- Because of the nature of the waste handled at the Hawkins Point Landfill, gas generation due to microbial activity is not a concern at this site.

- At the Virginia Beach Sanitary Landfill No. 1 (which has been closed for some 15 years), the proposed construction of remedial closure system incorporating a clay cap to minimize infiltration will necessitate the installation of a passive gas venting system. Because the site has been converted to a park, aesthetic considerations were a factor in vent design. Gas from this landfill will be vented through 25-foot tall stacks which serve the dual purpose of flag-standards for the park. (Engineering analysis indicated that because of the landfill age and size, the gas from this site was not sufficient in quantity or suitable in quality to allow economic recovery of energy; the gas for Landfill No. 2, however, will be collected and used as an energy source).

R&D Needs

- The issue of how to design an FML system or a leachate collection system to be compatible with a leachate whose characteristics are not known at the time of design. Because of the complex nature of leachate, manufacturers' charts of product compatibility with specific individual chemicals are of little help to design engineers in selecting suitable liners.

- Collection and dissemination of the experience from full-scale facilities (e.g., experience, if any, with the clogging of leachate collection systems).

- Evaluation of the most appropriate means for handling leachates from municipal landfills (i.e., what to do with the leachate once it is collected?). The evaluation should particularly address merits and demerits of the leachate recycling approach.

A.12 TECHNICAL DISCUSSION NO. 12

New York State Dept. of Environmental Conservation (DEC) :
E. Belmore , J. Coyle, M. J. Hans, F. Grabar

MEESA: M. Ghassemi

May 24, 1984

Leachate Collection

- Some siltation has been noted at the bottom of leachate collection standpipes (sumps) in the older designs employed previously at both the CECOS and the SCA facilities (in Niagara Falls and Model City, NY, respectively). The problem has been mostly in the cells dedicated to heavy metal sludge disposal. It has been attributed to the passage of fine particles through the gravel drainage into the collection pipe as well as possibly through the joints of the standpipe. In the newer units (SLF No. 5 at CECOS and SLF No. 11 at SCA, currently under construction), a graded filter media drainage blanket, which will cover the entire liner on the bottom, will replace the gravel-only drainage envelope and this should minimize the escape of waste particles to the collection pipe. The use of automatic level control, which has now been instituted (see below), should also eliminate the very long leachate residence times in the sumps, thus preventing substantial particle settling in the sumps.

- The depth of the sediment buildup in the sumps at both CECOS and SCA facilities seldom exceeded 2 ft. At both sides the problem was mitigated by use of a high pressure water hose which enabled pumping out of the deposit as a slurry. (At the SCA site, the use of a scooper to bucket out the deposit was also considered but rejected in favor of the slurry pumping method). As far as DEC can determine, sediment accumulation in the sumps was never a major problem at either sites, and cleaning was only required 2 or 3 times over a 3-4 year period.

- In the past the pumping of the leachate from the sumps has been on an infrequent basis and this at times has resulted in excessive leachate accumulation in the sumps and very high (perhaps as much as 10 to 20 feet) heads in the landfill. Automatic leachate pumping whereby the leachate level in the sumps will always be maintained lower than a certain level, would thus (a) eliminate excessive head buildup in the sump and the landfill, (b) reduce the potential for long leachate residence time in the sump and (c) increase leachate flow to the sump by decreasing the back pressure due to high leachate levels in the sump. This last assertion is supported by the leachate monitoring data (see Figure 19) which indicates an increase in the observed leachate volume upon installation of an automatic leachate pumping system.

- At the SCA's SLF No. 11, the automatic leachate withdrawal system will be electrically controlled and will consist of a pump in each sump, high and low automatic controls, and a high level alarm. The system is thus designed to drain leachate from facility without building up a storage head above the lining system. Each pump will turn on when leachate levels in the sump have accumulated to the invert of the incoming collection pipes. The high level alarm will be installed at a level of one foot above the drainage blanket to alert plant personnel of possible malfunctioning equipment.

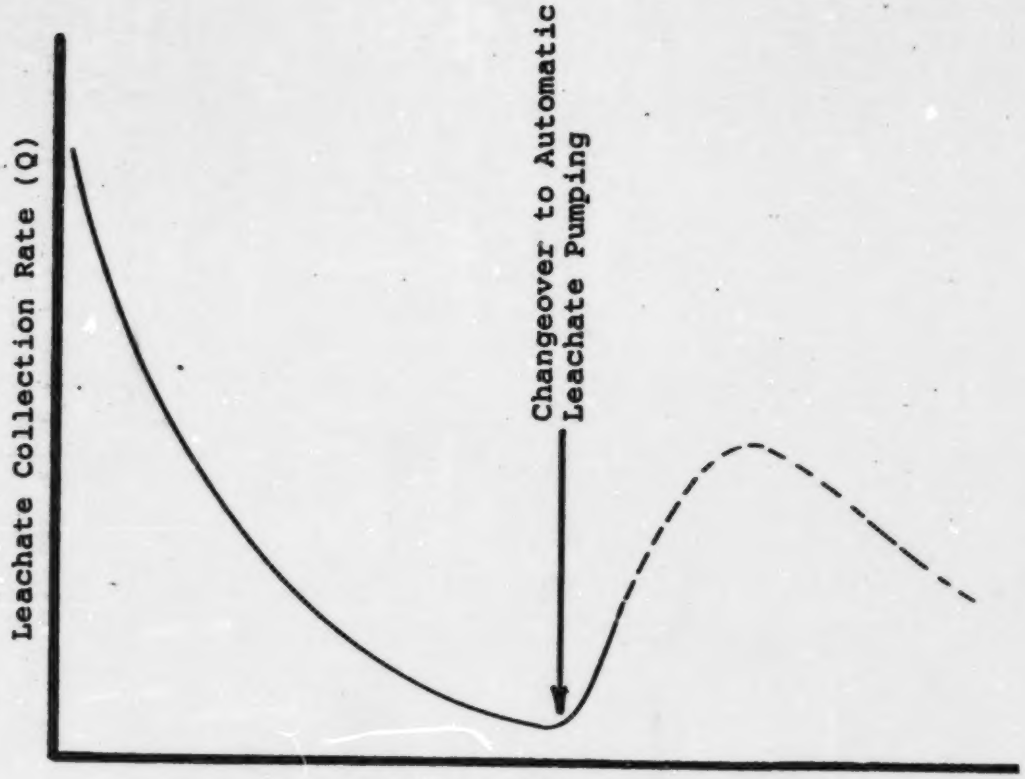

Figure 19. Effect of installing level-activated automatic leachate removal system on the volumetric rate of leachate collected

- At some older landfill units at SCA where water treatment sludges had been used as intermediate covers, there was some evidence of leachate perching in the landfill. To eliminate the problem at the currently active and future units, DEC now requires SCA to use cover materials with a permeability greater than 10^{-3} cm/sec in at least every fourth lift and greater than 10^{-4} cm/sec for all other lifts. The breaking of the previous cover was considered as a means for eliminating the potential for leachate perching but was rejected as impractical given the likelihood for disturbing the carefully placed drums. To prevent hydraulic continuity of the intermediate cover, one consultant had suggested the use of a grid system whereby cover materials having a range of permeabilities would be used on different sections of the same lift.

- Since berms are usually wider than designed, the excess clay is removed prior to waste placement. If this clay is used as cover material, it can interfere with effective leachate drainage within the fill.

- Other means for facilitating downward movement of leachate include placing gravel or similar material around the standpipes in a vertical column which will be extended upward as more lifts are placed and the landfill surface is raised. This design is featured in CECOS' SLF No. 5, currently under construction. The extent of difficulty in erecting and maintaining the gravel column around the standpipe remains to be determined. It is possible that any construction difficulty could be eliminated via use of wire mesh to retain the integrity of the gravel column.

- French drains (see Figure 20) have been used as the leachate collection laterals at the SCA's SLF No. 10. To improve the leachate collection effectiveness, in SLF No. 11 these french drains will be replaced with 4 in. diameter slotted HDPE pipes embedded in 1-ft. deep layer of gravel conforming to NYSDOT specifications for Class 1A (90 to 100% by weight passing a 1/4-in. screen and 0 to 15% by weight passing a 1/8-in. screen). The gravel layer, which will cover the entire landfill floor, will be placed on top of 1-ft. of clay compacted on top of a geomembrane. The slotted HDPE pipes will have a minimum grade of 0.5 percent and will be spaced approximately 73 ft. apart to divide each subcell into four approximately equal areas.

- There has been no reported incidence of damage to standpipes caused by the operation of landfill equipment at either SCA or CECOS site. The 48-in. standpipe is constructed of sections which are added as required during the operation, with the top of the pipe always maintained above the working grade and visible to the equipment operators. The pipe sections are bolted together and provide a very sturdy structure capable of sustaining any accidental bumping by equipment, which are generally small drum pickers (and not very large equipment).

- New designs at both CECOS and SCA facilities (SLF No. 5 and SLF No. 11) include collecting the leachate from various cells into a single main sump from which the combined flow will be pumped out. Each cell, however, has its own standpipe and sump system, if leachate segregation and separate removal become necessary. Based on past experience, the leachates from individual cells are very diluted and mixing them together should not present any incompatibility problem. A single pump in a main sump would be much easier to maintain than several pumps in individual cell sumps.

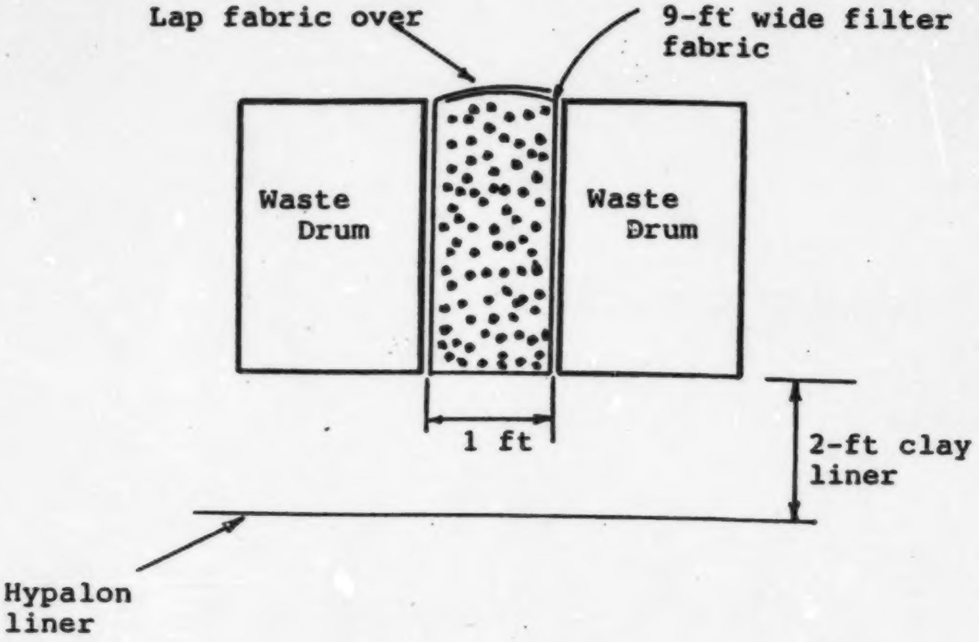

Figure 20. French drain leachate collection lateral at SCA SLF No. 10

- A geotextile filter fabric (Murafi 140N) had been considered for use in the SFL No. 5 at CECOS. The fabric would have been placed over the top of the gravel blanket to minimize penetration of the blanket with waste particles. This use of geotextile, however, has not been approved because of lack of experience and hence reliable standards for design. The SLF No. 5 design, however, incorporates use of a filter fabric (Murafi 700X) as a separator between the liner protective clay layer and the gravel drainage layer.

- At both CECOS and SCA facilities, there have been some occasional problems with the freezing of the leachate collection lines located near the surface during winter conditions. The problem has now been corrected by locating the pipes in sufficient depths and designing lines for gravity flow.

- Waste handling and placement practices would have significant impacts on the amount of leachate produced and its characteristics and hence on the design and performance of the leachate collection (and the liner) system. The state is very strict on this point and has inspectors at the site to ensure compliance with waste handling requirements, which are written into a facility's operating permit. In addition to the requirements for disposal of wastes into different cells (or in different areas within a cell) according to waste class (or subclass), there are restrictions on what wastes can or cannot be accepted at a site. For example, wastes containing more than 1% free cyanides, or having a reactivity ranking of greater than "3" (under the NFPA definition) are rejected. Wastes containing high levels of sulfide and cyanide are diverted to certain treatment facilities in the state which can handle such wastes.

- To protect the liner, attention is now being directed toward placing restrictions on organic wastes allowed in landfills, especially wastes which would separate into a two-phase system upon storage and/or reaction with other wastes, with the organic phase being the heavier (bottom) layer. Two-phase system wastes are produced by some of the local industries. As a result of the recent public hearings on proposed expansion of the SCA operation (i.e., construction of SLF No. 11), SCA has been required to conduct some waste/leachate-liner compatibility studies including evaluation , in a test cell, of the impact of waste/leachate on clay liner permeability.

Gas Control

- Although actual verification not available, it is very difficult to imagine any significant biological activity at a strictly hazardous waste disposal site such as the SCA or the CECOS facility, primarily due to waste toxicity and the harsh disposal environment. Accordingly, biological decomposition gases, which would require control at municipal or co-disposal sites, are not expected in a strictly hazardous waste site.

- Both SCA and CECOS sites have gas venting systems installed at their closed landfills. Currently the vent pipes are capped, but can be connected to a gas collection and treating system, if such a need ever arises. The vent pipes are fitted with manual gas sampling valves. The primary purpose of the gas venting system is to provide safety pressure relief during emergencies.

- Since the leachate collection sumps/standpipes are open to the atmosphere, there is a potential for emission of some volatile organic constituents present in the leachate, which may pass into the air space above the leachate surface. At the present time, there are no accurate and reliable protocols for sampling emissions from standpipes. Using data on the concentrations of ten volatile organics in an actual leachate sample, and a number of assumptions including the applicability of certain gas transfer equations, an ambient air temperature of 70°F, an ambient pressure of 1 atmosphere and a wind velocity of 4 m/sec, the total probable emissions from the five leachate standpipes at SCA's SLF 11 have been estimated to be as follows:

Compound	lb/yr
Acetone	499.3
Benzene	4.835
Carbon tetrachloride	11.76
Chloroform	10.03
Ethyl acetate	9.723
Ethyl amine	1997
Methanol	1159
Phenol	0.959
PCB	0.001
Toluene	13.00

- At the public hearings for the proposed expansion at the SCA Site, there was considerable public concern on air emissions from the facility. However, because of multiplicity of the sources of air emission at a complex facility such as SCA, it would be very difficult to assess the significance of air emissions (if any) from a particular landfill cell.

R&D Needs

- Evaluation of the performance of the graded filter in a leachate collection system as a function of the type of waste handled.
- Evaluation of the effect on leachate collection system performance when clay or sludges are used as intermediate cover (is it a problem and to what degree?).
- Evaluation of means for improving leachate drainage such as extending the drainage blanket to also cover the side slopes.
- Development of reliable protocols for sampling air emissions from leachate standpipes.
- Development of practical means for detecting leaking landfills.

Miscellaneous

- DEC does not have strict criteria on design and operation of hazardous waste facilities, and the requirements are established on a case-by-case basis. At CECOS and SCA there have been considerable changes in design and operation over the years as the result of the experience gained from operating various units and from the general advances in waste management technology. The following changes in the design for the various landfill units at CECOS illustrate this point:

-SLF No. 1, built in 1976, had no leachate collection pipes at the bottom; the landfill bottom was sloped to allow leachate flow to standpipes. There was no cell subdivision within the landfill to allow segregated disposal of waste by class.

-SLF No. 2 was divided into three cells. Vitrified clay pipes were used at the bottom to direct flow to standpipes.

-SLF No. 3 has a design similar to that for No. 2, except that (a) the unit was subdivided into five cells, (b) an HDPE liner was used in the PCB cell, and (c) the leachate collection pipe was surrounded with gravel. A flexible hose which would be inserted into the standpipe from the top was used to pump out the leachate from the standpipe.

-SLF No. 4, built in 1981-1982, had a drainage blanket extending over the entire bottom. The empty spaces between the waste drums placed on the bottom were filled with gravel up to a depth of 2/3 of the drum height. SLF No. 4 was also the first landfill to have side riser as well as automatic leachate removal system based on the leachate level in the standpipe.

-SLF No. 5, currently under construction, will have one foot of gravel over the entire bottom, below the "drum-gravel layer". No bulk loads will be allowed in the first lift.

- The leachate from some municipal landfills can potentially present equal if not greater hazard to environment. DEC now requires that all new municipal landfills be lined. Leachate monitoring requirements are also being extended to municipal landfills.

A.13 TECHNICAL DISCUSSION NO. 13 (SITE A)

MEESA: M. Ghassemi

May 23, 1984

Leachate Collection

- The clogging of the leachate collection system has not been a major problem nor expected to be a significant problem at SITE A because of the special design and operating procedures employed (see below). The only problem which has occurred in previously active landfills is some silt accumulation in the leachate collection sumps/standpipes which resulted in burning up of electrical pumps. The problem has been resolved by use of better pumps. The siltation has been attributed to lack of suitable gradation in the drainage envelope to retain fine particles (originating from some inorganic sludges). Siltation, however, was never more than a periodic nuisance which could be effectively dealt with by stirring using a water jet from a fire truck available on-site. The rapid increase in the leachate level in the sumps and the absence of ponding on the surface of operating landfills after major storms have been assumed to indicate that the drainage layers had not been blinded by silt accumulation.

- Based on monitoring of the leachate flow from closed units, and considering the improvements which are now incorporated in the design of the new units (e.g., at SCMF currently under construction), SITE A estimates that the leachate flow from new units should essentially cease within 5 years of site closure. (Flow from a SCMF closed in 1978 now averages about 75 to 100 gallons per day).

- In general, the best approach to the management of leachate and elimination of any potential for leachate collection system failure is to operate the landfills in as dry a condition as possible. This can be done through a combination of good design and operating procedures, including proper waste handling and placement practices. The following, which are featured at the SITE A facility, would reduce leachate volume and potential problems with the leachate collection system:

Design Considerations--

-Use of effective covers and surface drainage features to reduce water entering landfill.

-Multiple cell designs to allow for separate disposal of wastes according to some general waste categories (e.g., metal sludges, pseudometals, flammables, pesticides, etc.).

-proper design of the leachate collection and conveyance systems to facilitate flow of the leachate to the collection sumps. (key design features of a new SITE A SCMF are depicted in Figures 2 and 3; in this design, leachates from various cells are directed to a common sump for removal. Even though compatibility studies have indicated no problems with combining leachates, leachate from each cell can be pumped out separately, as a contingency measure).

Operation Considerations--

-Not accepting liquid wastes in landfills. (At the SITE A facility, liquid wastes are solidified before placement in the fill).

-Use of permeable material (sand, foundry ash, slag, etc.) as the intermediate cover material to prevent leachate perching within landfill.

-Use of materials such as lime and ferrous sulfate in the intermediate cover or to surround specific waste loads to effect immobilization.

-Removal of rainwater entering the active cells. (At the SITE A facility, this water is considered contaminated and is processed as leachate in the on-site wastewater treatment plant.)

- Consistently maintaining the leachate head over the liner to less than one foot, as required per RCRA interim regulations, has been a problem at SITE A. There is also a question as to where the one-foot head should be measured considering the fact that there is a slope to the liner.

- Where to put the leachate has been a problem at some sites. SITE A has on-site facilities for treatment of leachate and has a permit from the state for temporary on-site lagooning of the leachate in the case of an emergency during periods of heavy precipitation.

Gas Control

- Biological activity is suppressed (and perhaps nonexistent) at strictly hazardous waste landfills and hence no significant amounts of deocmposition gases would be expected. Gases may evolve, however, as a result of volatilization or chemical interaction if the wastes are not properly pretreated or emplaced.

- The landfill units which are closed at SITE A are provided with gas venting pipes (See Figure 6). Periodic monitoring of the gas pressure at these vents (which are capped) has indicated no gas pressure buildup. This is understandable due to the toxic nature of the wastes handled and the practices of waste pretreatment, in-place neutralization/immobilization and segregated disposal of different waste categories. SITE A does not accept any putrescible wastes in its hazardous waste landfills.

- SITE A has a source emission permit from State covering all leachate standpipes as well as the gas vents.

R&D Needs

- Establishment of basis for design of drainage filter gradation system taking into account specific waste properties such as particle size distribution and mobility. (As noted above, SITE A experience indicates that heavy metal sludges exhibit a greater potential to penetrate and move through the leachate collection drainage envelope than other wastes handled at the site.

- Development of detailed specifications and guidelines on waste disposal site design and operation. Such specifications should not provide arbitrary standards (as is commonly done in regulations) but rather provide basis for engineers to develop solutions to site- and situation-specific conditions.

A.14 TECHNICAL DISCUSSION NO. 14

Wehran Engineering : Salvatori Arlotta

MEESA: M. Ghassemi

May 25, 1984

Leachate Collection

- There have been considerable changes and improvements in the leachate collection system design over the years. The progression of technology spans the use of toe drains only in the older systems, the use of gravel drains and fabric filters in later designs and the use of conventional sand and gravel filters in the latest designs.

- Wehran has used geotextiles as filter media in some municipal landfill leachate collection systems. Even though the length of experience is not significant, so far there are no indications of a clogging problem at these installations. Wehran's philosophy is now not to use fabric filters for hazardous waste sites at all, but instead rely on traditional graded filters for which the technology is better known.

- With the older systems, leachate heads of 10 to 15 ft. or higher within the landfill were not uncommon. In the latest designs, however, even though there may be some buildup of leachate head within the waste mass, the actual head on the liner itself may be very small or negligible. In these designs, the permeability of the drainage blanket far exceeds that of the waste and the leachate level in the collection sump is maintained at or below the invert of incoming collection pipes (via automatic level-activated pumping), thus preventing a build-up of leachate storage head above the liner. Under these conditions, an air gap layer (an "unsaturated zone") will always exist within the drainage blanket, limiting the head on the liner to that due to the fluid level within the blanket. This air gap design has been used by Wehran in two installations which are now in operation, and one installation which is under design.

- The potential for clogging of the leachate collection system is very low or essentially non-existent with the new designs, because of the considerable built-in redundancies. These redundancies relate to (a) the oversizing of the pipes, thus providing for a much greater carrying capacity than the actual or anticipated flows, (b) availability of alternate flow routes (e.g., other laterals, in the event that one or more laterals become clogged, (c) provisions for cleaning access to pipes, and (d) the flow carrying capacity of the drainage blanket itself which makes a positive connection across the entire base of the landfill.

- With the present day cover design and construction technologies, little rainwater is expected to enter a landfill after it is closed. The leachate which is pumped out after closure is essentially the water which entered the site during waste placement. The goal of having a dry landfill can thus be achieved more quickly, if the size of an active landfill cell (area) is limited to that which can be filled and closed within one to two years. This cell-by-cell "progressive" design and operation approach also provides for some experimentation and enables design modifications to incorporate the experience from preceeding fill operations (or other advancements in the general landfill technology).

- In addition to improvements in the operation, progressive design can result in significant cost savings. For example, the experience from the CECOS SLF No. 4 indicated that leachates from individual cells are compatible and can be combined prior to pumping. Thus, in SLF No. 5, currently under construction, the leachates from various cells will be directed to a common sump from which the mixed flow will be pumped out. This will eliminate the need for multiple pumps to separately remove leachates from individual cells, thus reducing both the pumping cost and the maintenance required.

(At SLF No. 5, each cell would have its own standpipe and side riser which can be used for leachate segregation and separate removal, in the event that such action become necessary in the future. The option of initial design for pumping of the combined leachate via single pumping system has been offered by Wehran to some of its clients at other sites; in some instances, the clients have preferred separate pumping for individual cells, presumably due to improved leachate management control.)

- To promote the concept of progressive design, some changes to permitting procedures may be necessary. Under the present permitting system, a new permit would be required for design changes which would be considered as "significant" modifications. To avoid obtaining a new permit (which involves very complex procedures and requires public hearings as part of the approval process), the designs which are actually constructed are often several years old and do not necessarily incorporate the state-of-the-art. An ideal permitting approach is one which would issue only one umbrella permit for the entire site, with modifications to designs requiring only state review and approval (and not a new permit and attendant public hearings).

- Placing drums containing wastes which would not readily mobilize (even if the drum fail) at the very bottom lift is an excellent approach to minimizing some of the leachate and leachate collection system problems. However, adequate number of suitable drums are not always available at the time that the first lift is placed and the operators use whatever drums (or bulk wastes) which are available to them at the time. The situation can be improved if the regulatory agencies allow the operators to keep on hand (i.e., to temporarily store on site) an adequate number of drums containing suitable wastes.

Gas Control

- At strictly hazardous waste disposal sites such as the SCA or the CECOS site in New York, there would be essentially little or no potential for biological activity due to the toxicity of the waste and the operating practice of not accepting putrescible material. Thus biodegradation gases, such as methane, which are produced at municipal and co-disposal sites, and which require migration control, are not encountered at strictly hazardous waste sites. At co-disposal sites there is also a potential for the emitted gas to pick up and carry some hazardous constituents.

- The potential for emissions from landfills was a greater concern some years back when there were inadequate restrictions on the type of wastes accepted.
- The cover systems designed for hazardous waste facilities are generally provided with gas-venting pipes which can be hooked up to a gas cleaning system in the event that emissions control becomes necessary.
- The state requirements for emissions and ambient air monitoring at certain sites have primarily stemmed from public concern rather than actual data indicating emissions of hazardous constituents. (Some cursory, "one shot" analysis of the emissions from standpipes at a hazardous waste landfill unit at a client site has indicated no emissions of any consequence from this source).

R&D Needs

- Case studies of design versus performance for the leachate collection systems in actual full-scale use. Such studies can provide information on permeability of various wastes relative to that of the drainage envelope and thus correlate the leachate head in the waste with that in the drainage layer. Significant cost savings and improvements in design can result if the leachate collection systems can be tailor designed to handle specific waste types/placement practices.
- Demonstration of liner-waste compatibility using actual waste or leachate.

A.15 TECHNICAL DISCUSSION NO. 15

Emcon Associates: Fred Cope, John Pacey, Robert Van Heuit

MEESA: Masood Ghassemi, Kimm Crawford

29 June 1984

Leachate Collection

- With the reference and guidance documents which have been made available to the designers in recent years (e.g., the EPA Technical Resource Documents), engineers now feel more comfortable with the design of leachate collection systems.

Extensive experience with and feedbacks from systems which have been placed in service in recent years are not yet available; little problems, however, would be expected with these new systems which have followed the recommended guidelines. Although there still remains certain uncertainty and gray areas (e.g., as to the needed adjustments to the pipe design equations, which have been developed for clay tiles in construction drainage applications but are used to design plastic pipes for leachate collection), the opportunities for avoiding mistakes are far greater today than they were previously when the older systems were being designed.

- Much of the documented problems with the existing leachate collection systems relate to older systems (primarily municipal or co-disposal sites), which lacked sophisticated designs, did not incorporate design redundancies, and in many cases consisted merely of simple toe drains, interceptor pipes or gravel drains, with no consideration for minimizing potential for siltation (e.g., through the use of fabric filters). These systems were also poorly constructed and received little or no QA/QC, with some lines already damaged or partially clogged before they went into service. Minimizing potential for leachate generation, removing the leachate from the landfill once it is produced, and providing easy access to lines for cleanout and preventive maintenance were not generally key design and operating objectives. The current practices, which limit or ban the disposal of bulk sludges and liquid wastes and set requirements on the type of material used for intermediate cover (to ensure low permeability and hence avoid potential for leachate perching) were not also observed in the previous practices at many older sites. Because of these considerations, the existing clogging or other experience with the leachate collection systems in the older systems would not necessarily be applicable to RCRA-designed sites.

- There has been little opportunity for corrective action at RCRA-designed hazardous waste landfills. Use of barriers such as a slurry trench to contain leachate, use of gravel trenches or pipes to intercept seepage, drilling caissons in landfills and pumping out the perched leachate, and replacing sections of the collection system (where the depth of the overlying waste is not significant) are among the corrective measures which have been used in older co-disposal sites.

- It is not appropriate to make comparisons between the performance of the agricultural drainage systems and the leachate collection systems because of the differences in design and construction of the two systems. Agricultural drainage tiles are designed for a much greater hydraulic loading and are wrapped in filter fabrics to minimize clogging. PVC or polyethylene pipe used for leachate collection should not normally be wrapped in such filters.

- Because of the establishment of certain regulatory operating and performance standards (e.g., the RCRA requirement for maintaining a leachate head of less than 1 ft above the liner), there will be a greater uniformity in future designs. Engineering judgement and use of special features, however, will continue to govern the detailed design which must take into account job-specific considerations and the preference and experience of individual designers. On many jobs, for example, Emcon has specified specially-fabricated pipe connectors for the leachate collection system to promote better access for maintenance purposes. Based on its experience, Emcon prefers the use of slotted pipes over perforated pipes as leachate collection laterals. Emcon uses geotextile as a separator to line the interior of gravel trenches, thus allowing the use of coarser gravel in the trench. Any proposed overlapping arrangement of geotextile to cover the gravel mound on top of the trench is evaluated for potential clogging of the geotextile, which can lead to poor drainage.

- Controlling the amount of rainwater which would enter a landfill during active life would reduce the volume of the leachate which would be generated. Some sanitary landfills have successfully used tarps as a temporary cover (e.g., in lieu of the daily cover) to divert rainfall from the active surface. Storage of the processed (e.g., solidified) waste in a roofed storage area during rain for transfer to landfill when the weather improves would reduce quantity of water contacting waste and hence the leachate production.

- From the standpoint of an overall site performance, the potential for liner system failure is of much greater concern than the possibility of a leachate collection system failure.

Gas Control

- With the present practices and the trend toward stricter source control, gas generation and migration/emissions control are not of much concern at strictly hazardous waste facilities which are designed per RCRA requirements. At such facilities, emissions from pretreatment and waste processing activities, which preceed the actual waste disposal, would perhaps be of greater concern than emissions from waste placement and/or the landfill after it is closed. Even if some waste volatilization and degradation occur in a RCRA-designed site, the internal gas pressures at these sites are not very high to effect gas migration by a convection mechanism and the cover system will have sufficient adsorptive capacity to prevent significant emissions of volatile toxic substances to the atmosphere.

- Because of the very high cost of disposal in hazardous waste sites, there is a conscious attempt on the part of the industry to reduce volume of waste destined for land disposal. Thus the trend is toward greater material recovery and equipment/process modification to affect waste quantities and characteristics. To avoid operating problems, the site operators also exercise considerable control over the type of waste which they place in a landfill. Thus to avoid gas generation, which can be damaging to the integrity of the cover after the site is closed, decomposable wastes and bulk liquids are not admitted to a hazardous waste site. Volatile substances are removed or passified through proper pretreatment. In California, the disposal space in Class I and Class II sites, which can accept hazardous wastes, is a premium space and it would be foolish to use these sites for the disposal of wastes which can be handled more economically by other means.

- Because of the above considerations, source control appears to be the most effective and the future trend for the control of emissions from hazardous waste sites. Based on information from industry and the thinking in the state regulatory agencies, it appears almost definite that, at least in California, waste solidification prior to disposal will become a prevalent practice. Solidification may not totally prevent loss of volatiles from a waste, but would certainly reduce it significantly. There will also be more restrictive requirements for source control, including more detailed waste documentation and the use of a three dimensional grid system to identify the exact location of a waste load within the landfill.

- Again, because of the above considerations, Emcon has not incorporated gas collection and treatment in the closure plans for any hazardous waste sites which it has designed. Up to now, Emcon has also not done any emissions monitoring at these sites. Leachate off-gases can only be a potential source of intermittent emissions since in all Emcon designs sumps and cleanout accesses are capped and may present a potential for emissions only when they are opened for inspection and maintenance. In this regard, the safety of the maintenance personnel rather than the potential for atmospheric emissions has been the primary concern.

- Gas generation and migration control problems are primarily associated with co-disposal and municipal sites where the waste undergoes degradation and the high pressure of the decomposition gases can cause gas migration and atmospheric emissions. Although all possible mechanisms are not known, the hazardous constituents present in the gas from these landfills can originate from waste volatilization and/or degradation (e.g., vinyl chloride from degradation of plastics or toxic vapors from volatilization of solvents contained in plastic manufacturing wastes.). Since municipal landfills receive various quantities of hazardous wastes (e.g., from small volume hazardous waste generators), it is not surprising that compounds such as benzene, toluene, xylene, which have been identified as trace constituents in the gas from co-disposal sites, have also been found in the decomposition gas from the so-called municipal landfills. It thus appears that the differences in the composition of gas from municipal and co-disposal sites are a matter of degree rather than kind. Gas and emissions control systems and procedures for the two landfill types would also be the same in fundamentals but vary in complexity and details. In general, passive control systems would not be an acceptable emissions control (at least at co-disposal sites) since any toxic substances in the gas would still be released to the atmosphere.

R&D Needs

- Use of geotextile in waste disposal application is of considerable interest and hence worthy of more detailed investigation. Provided that it meets the compatability and longevity requirements, and can provide in-plane permeability, geotextile may be potentially a far more suitable media than the conventional sand and gravel filters.

- There is a need for additional leachate-liner compatability data. At the present time designers have to rely primarily on liner manufacturers' data and claims, much of which will need to be independently verified.

- The regulatory, economic and legal considerations have brought about significant changes in the nature and make-up of the wastes now destined for land disposal. A study which would better characterize the type of wastes which are now sent to disposal facilities and the expected future trends can be very helpful in improving site design and operating practices to reflect these changes and trends.

A.16 TECHNICAL DISCUSSION NO. 16

Getty Synthetic Fuels, Inc.: L. Collings, J. Pena, W. Taylor

MEESA: Masood Ghassemi, Kimm Crawford

10 July 1984

Gas Control

- Getty Synthetic Fuels, Inc. (GSF) bases its decision to develop a landfill gas recovery project primarily on data obtained during testing and on technical ability to profitably produce acceptable product gas. In general, however, because of the need for additional gas processing to meet product specifications (e.g., for pipeline gas), GSF has intentionally stayed away from landfills which have received significant quantities of hazardous wastes, unless the hazardous waste disposal has been in a confined section of the landfill which can be excluded from contributing to the collected gas. Only two sites which have accepted large volumes of hazardous wastes have been included in GSF's landfill gas recovery projects. These are the Palos Verdes Landfill in Rolling Hills Estates, California, which was the first site for a GSF project, and CID Landfill in Calumet City, Illinois, where the hazardous waste disposal has been confined to isolated sections of the landfill. With the availability of a large number of municipal landfills from which substantial quantities of relatively clean gas can be extracted, GSF has not seen a justification to even consider extracting gas from sites which have received substantial volumes of hazardous (especially liquid) wastes.

- As part of its market assessment program and in connection with its various gas recovery projects, which now span some ten years, GSF has conducted extensive field surveys of landfills to determine their suitability for gas extraction and/or develop a basis for gas recovery and processing system design. These efforts have involved drilling in the landfills to determine the profiles of in-place wastes, detailed chemical analysis to determine gas composition, sampling and characterization of the incoming waste, and examination of the historical record on the quantity and types of various wastes admitted. The extensive data base which has thus been developed indicates that the quantitative yield and the quality of gas (e.g., the gas composition with respect to trace constituents) are highly variable and extremely site-specific and that these variations are not necessarily related to the regulatory or conventional classification of sites as municipal,, municipal/industrial, sanitary co-disposal, etc. It is because of this extreme site-specificity that the final selection of a site for gas recovery is preceeded by extensive site evaluation. This evaluation and the development of the basis for gas recovery and processing are very expensive and time consuming. The on-site testing and sample collection alone take 3 to 4 months at more than $250,000 per site. An additional 4 to 5 months of laboratory analysis of the refuse and the gas samples, and computer modeling of results may increase the actual total cost to $500,000 per site. Failure to recognize the need for detailed site evaluation and the requirement for tailoring of the design to the specific gas characteristics has resulted in a number of costly failures (e.g., involving lack of gas for processing, unanticipated gas declines and extensive corrosion of equipment).

- Although significant problems with equipment corrosion were encountered in the early gas processing projects (e.g., initially at the Palos Verdes site), GSF now has developed the know-how for addressing the problem and no longer considers corrosion a major design problem for new plants. The gas treating systems which have been developed are capable of removing chlorinated organics and sulfur-containing compounds to levels which would meet product specifications and would not present corrosion problems. These systems are equipped with pollution control devices and provide for safe disposal of pollutants removed from the new gas.

- Based on analysis which it has conducted, GSF projects only a slight change (10 to 15% increase in organic content) in the composition of wastes entering municipal landfills between now and the year 2000. As long as landfills which are candidates for gas recovery have to be evaluated on a case-by-case basis, small changes in the overall composition of wastes entering landfills would be of little significance from the standpoint of project planning and design.

- In connection with and in support of its gas recovery projects, GSF has developed extensive computer models of gas generation and migration in landfills. These models are considered valuable tools and are used by GSF for first order approximation in connection with assessing project feasibility, plant sizing, screening design options and preliminary cost analysis.

- Unless the gas from municipal landfills is recovered, in addition to the safety hazards associated with off-site gas migration, landfill gas can constitute a major source of air pollution. Since landfill covers can only postpone gas emissions (i.e., after steady-state conditions are reached, soil covers are ineffective in preventing gas escape), landfills can emit large amounts of reactive organics and substantial amounts of potentially hazardous substances which are present in the landfill gas as trace constituents. For example, before installation of gas collection for energy recovery/disposal at the Puente Hills landfill near Los Angeles, this landfill was the single largest stationary point source of hydrocarbon emissions in the Los Angeles basin. Because of these considerations, gas recovery, which significantly reduces uncontrolled emissions, appears the most logical pollution control approach which at the same time enables recovery of energy. Although the hydrocarbon content of landfill gas is very site specific and is found in a wide range of concentrations, a very rough estimate would indicate that for every 4 MMCF of landfill gas recovered for processing, about 1 ton per day of reactive hydrocarbon emissions may be eliminated.

R & D Needs

- Source testing and monitoring at municipal landfills to expand the current data base on emissions from landfills and their air quality significance.

- Evaluation of means for promoting the concept that landfills are point sources of emissions and that the gas recovery is the "pollution control device" for landfills. Such studies should include identification of regulatory approaches (or changes to existing regulations) which would promote gas recovery and enhance cost-effectiveness of gas recovery projects. Some regulatory considerations which can encourage gas recovery projects are (a) consideration of gas recovery system not as a new source for regulatory purposes but as a control device for an existing source (i.e., the landfill), thereby allowing the use of "bubble concept" to give a "credit" to gas recovery facilities for the emissions reductions they create at landfills; (b) allowing return to the landfill of condensate moisture which results from landfill gas processing; (c) use of "performance" (as opposed to "equipment" or "process") standards to allow and encourage private sector innovation in landfill methane recovery; (d) simplifying the permitting process so that project development can proceed expeditiously; and (e) separating the permit for the gas recovery and treating operation from the permit from the landfill operation so that regulatory actions against landfills will not necessarily shut down the gas recovery operation and hence aggravate the problem. These regulatory considerations have been discussed in detail in the following paper by Mr. William R. Taylor of GSF: "Regulatory Barriers to Landfill Gas Recovery Projects"; paper presented to Distribution and Transmission Conference, American Gas Association, San Francisco, CA, May, 1984.

APPENDIX B

CORRECTIVE AND PREVENTIVE MEASURES FOR COVER AND BOTTOM LINER SYSTEMS

B.1 BACKGROUND AND OBJECTIVES

As noted in Section 1, the technology for constructing and installing cover and bottom liner systems for LFs and SIs was recently evaluated in two studies for EPA (1, 2). These studies, which identified a number of problem areas and analyzed applicable preventive and corrective measures, used as data bases the published literature and information collected through some 50 face-to-face interviews with liner manufacturers, fabricators and installers, design engineering firms, active researchers, hazardous waste management facility owners and operators, and state regulatory agencies. One of the studies (2) also included nine SI case studies whereby the actual site performance was compared with that projected based on design and reasons for any deviations (or lack of deviations) were identified.

Although liner and cover systems were not the focus of the present study, the data acquisition effort generated some additional information on actual or potential problem areas and approaches for preventing or correcting them. For the purpose of completeness, the results from the previous studies as well as the information collected in the present study relating to liner and cover systems problems and applicable corrective and preventive measures are presented here in this Appendix. (The summary and conclusions and recommendations sections of the two predecessor studies are reproduced as Sections B.3 and B.4).

B.2 LINER AND COVER SYSTEMS PROBLEMS AND APPLICABLE MEASURES

Table 20 presents a summary of liner and cover systems problems and applicable preventive and corrective measures. Two problem areas which have been of considerable concern and which were suggested by a number of individuals with whom technical discussions and interviews were held in the present and the predecessor studies as requiring additional R&D relate to (a) liner leak detection and repair, and (b) cover settlement. These two areas are briefly reviewed below.

B.2.1 Liner Leak Prevention vs. Detection, Location and Repair of Leaks and Restoration of Groundwater

At the present time there is no reliable, practical and

TABLE 20. EXAMPLES OF LINER AND COVER SYSTEMS PROBLEMS AND APPLICABLE PREVENTIVE AND CORRECTIVE MEASURES

Problem	Preventive/Corrective Measure
General problem areas (both clay and FML):	
Poorly written and difficult-to-follow specifications and guidelines	Requiring (educating) designers and suppliers to write lucid and easy-to-follow specifications.
Inadequate QA/QC	Developing and implementing adequate QA/QC at all steps of design, construction, installation, and operation of facility.
Liner-waste/leachate incompatibility	Selection of suitable liner based on literature data, manufacturer's information, actual or estimated waste characteristics, liner-waste compatibility testing.
Locating leaks	Use of methods (some still in the developmental stage) for leak detection; examples: water balance for surface impoundments, electrical conductivity method, use of observation wells, groundwater monitoring, visual inspection of caps.
Facility foundation (both clay and FML):	
Compaction to less than the required density (resulting possibly in later differential settlement which can induce stresses in the overlying liner)	Use of the state-of-the-art earthwork techniques and practices; and an adequate QA program to ensure that such practices are actually utilized.
Permitting the foundation to develop a moisture condition that is incompatible with subsequent liner placement steps	
Inadequate surface finishing to reduce the potential for liner puncture (this is generally a concern for FML only)	
Inadequate sterilization of foundation soils to suppress the growth of vegetation which can potentially penetrate the liner	
Clay liners and caps:	
Where in-situ clays are involved - failing to detect and remove discontinuities from the clay such as sand or silt lenses, roots, rocks, etc.	Detailed soils investigation to determine the applicability of over-excavation and recompaction of the clay.
Where recompacted emplaced soil liners are used - inadequate protection of stockpiles from contamination	Covering stockpiles (or seeding for lenghty storage), inspection to detect and remove contaminants, and adjustment of moisture content.
Failing to attain the desired permeability which generally results from the difficulty of ensuring that conditions in the field closely meet those specified in the design specifications	Use of laboratory permeability tests for general guidance during final design in conjunction with field permeability tests on individual lifts and on the completed liner for construction verification.
Prevention of cracking, particularly by dessication, between the time that the liner is completed and when it is backfilled or put directly into service	Inspection of moisture content, destruction of large clay clods during construction; immediately after installation, placement of backfill, synthetic material, or fluid over the liner.
Flexural cracking of the cap during installation due to the operation of heavy equipment on spongy waste	Placement of additional lifts on an as-needed basis; reduce sponginess of waste fill by mixing soil or granular waste into soft wastes or reducing thickness of cells containing soft wastes.

(Continued)

TABLE 20. (Continued)

Problem	Preventive/Corrective Measure
FML liners and caps:	
Damage to liner material due to exposure to adverse weather, vandalism, and repeated folding and unfolding	Storing liner material in a secured area; reducing time between delivery and placement of liner; avoiding unnecessary folding/unfolding; and inspecting materials.
Placement of panels in a wrong configuration (e.g., seams on side slopes oriented parallel rather than correctly perpendicular to the side)	Identification of panels by number at manufacture and fabrication and strict adherence to design specifications.
Placements that bridge a gap between two surfaces (e.g., at penetrations)	Ensuring complete liner contact with supporting soil and proper subgrade compaction around appurtenances.
Improper anchoring (e.g., backfilling anchor trenches before seaming is completed)	Anchoring panel edges with sandbags before seaming; careful operation of equipment during anchor trench backfilling.
Improper timing (for example, placement during inclement weather, including windy conditions)	Avoiding installation during inclement weather and effective QA to ensure this; seaming and patching to correct most wind-related damage.
Placement of the liner with little clearance between it and the leachate collection pipes. This is often unavoidable per the requirements of the leachate collection system, but any ruptured pipe could potentially puncture the liner	Careful placement and compaction of drainage beds.
Inadequate seams resulting from use of inadequate seaming techniques, seaming during adverse weather conditions, seaming with inadequate materials, seaming new material to old liner material, and not paying special attention to seaming around penetrations	Strict adherence to the seaming procedures (e.g., type and amount of solvents, pressure applied to seams, etc.) recommended for the specific liner material at hand; use of experienced installers (at least at the foreman level); installation during suitable weather conditions.
	Removal of slack and wrinkles, except those included intentionally to allow for thermal expansion/contraction.
	Allowing enough time for the completed seam to develop strength before loading.
	Giving special attention to making connections between the liner and structures.
	Taking special precautions when new cap material is seamed to old liner material (e.g., ensuring that the bottom liner and cap are compatible when seamed, removing of the surface cure from the bottom liner using solvents and scrubbers, and repairing damage that the bottom liner suffers when it is uncovered).
Mechanical damage to liner during placement of backfill	Use of a minimum soil lift of 12 to 18 inches; careful operation of equipment on backfill; specify maximum weight to be driven on liner; use of temporary ramps for equipment to drive on and off the disposal unit.

foolproof testing and inspection procedure for determining all leaks (unless they are major ones) in a completed liner before it is placed in service or while in service. Although some R&D effort has been devoted in recent years to the investigation of innovative concepts for leak detection, such concepts have not yet been adequately developed for full scale application (see Section B.2.2). Leak detection is very difficult even in clean systems (e.g., lined water reservoirs) let alone liners used in waste management applications. Thus in acceptance inspection of completed liners, it is virtually impossible to detect all leaks (unless they are major ones) through standard tests such as evaporation rates for use in water balance calculations (T.D. No. 12). Inspection of entire subsoil for "soft spots" is also impractical. Thus the need persists for capabilities to develop installed liners which will not leak and for reliable techniques to detect, locate and repair leaks in operating facilities before the escaping leachate or waste can seriously damage the ground water. Although methods for control of ground water contamination are available*, these methods can be very expensive and may not be completely effective under all circumstances. Thus, prevention of ground water contamination is preferred over taking corrective action after the ground water has been contaminated.

Even if leaks can be detected in time in an operating facility, it may not always be practical or economical to repair the liner (e.g., when a significant volume of waste is already in place in a landfill or when a liner material such as Hypalon has undergone considerable curing due to aging).

Thus the best approach to eliminate leaks would be to strive for developing and maintaining leak-free systems in the first place. As noted in Sections B.3 and B.4 and in T.D. No. 2, the attainment of this goal requires execution of an effective QA/QC program which covers all aspects of liner design, manufacturing, fabrication and installation and includes use of reputable installers.

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*Ground water that has been contaminated can be dealt with in a number of ways. Impermeable barriers constructed of bentonite slurry, cement or chemical grouts, or sheet piling can be installed vertically to (a) prevent ground water from migrating away from the site; or (b) divert ground water so that contact with waste materials is prevented. Another potential method of dealing with contaminated ground water is to allow it to flow through permeable treatment beds (limestone and/or activated carbon) in which the contaminants would be removed as the ground water flows through the bed. The above two treatment methods can be considered passive ground water controls. The pumping of ground water with subsequent surface treatment is considered an active remedial measure. Pumping can be specifically designed to lower the water table in the area of a disposal site or it can be designed to contain a contaminated water plume.

B.2.2 Testing and Inspection to Prevent FML Failure

Features of FML installation which require testing and inspection to prevent liner failure include: subgrade preparation, material handling and storage on site before placement, placement, seaming, anchoring, connecting to appurtenances and backfill placement. Some examples of the inspection and testing procedures applicable to these features (except for the seaming which is reviewed below) are presented in Tables 21 and 22.

Seaming, especially the field seaming, is one of the most critical steps in FML installation and the seam integrity generally determines the integrity of the entire job. A brief discussion of the factors involved and the current experience and philosophy in testing field seams is presented below to illustrate the type of information which is available. Some of the tests and inspection procedures (e.g., visual inspection, vacuum testing, shear strength and peel adhesion) are equally applicable to factory seams which are done under more controlled conditions and hence are generally viewed as less subject to defects.

Different types of tests are available to measure various seam properties and for various seaming systems. These tests fall into two general categories, non-destructive (qualitative) and destructive (quantitative). A good quality control program will include tests of both types, since no one test is foolproof The recommended procedure requires that all field seams be non-destructively tested over their full length. This non-destructive testing should include both visual inspection and at least one other applicable method: air lance, vacuum, or ultrasonic testing. It should be done as the seaming work progresses, not at the completion of all field seaming. Visual seam inspection includes the following steps: checking the width of the seam overlap, inspecting for any defects such as blisters, tears, etc.; and checking for exposed scrim at the edge of each panel.

HDPE seams are usually tested with a vacuum or ultrasonic test unit; butyl, PVC, CPE and related material seams are usually tested with an air lance or vacuum test unit. Vacuum testing is not considered to be as reliable for thin, flexible materials as it is for thick, stiff materials. Some liner installers feel that because HDPE welds are designed to be homogeneous, inhomogeneities such as gaps, bubbles, and holes in the welds are easily detected by ultrasonic testing. It has been reported that on one job, one mile of seaming was checked and the ultrasonic test was in error on only four inches. However, ultrasonic methods are generally not capable of detecting a seam holiday less than one millimeter in size and the reliability of ultrasonic test methods

TABLE 21 TESTING AND INSPECTION FOR SUBGRADE PREPARATION AND MATERIALS AND EQUIPMENT

Criteria/ Element	Problem/ Concern	Testing and Inspection
Particle size	Liner puncture	-Visual inspection to verify removal of as many rocks, sticks from the subgrade as possible before placement of additional materials -Checking of the soil to be placed as subgrade to ensure it is free of any objects that might damage liner -Grain-size distribution (e.g., via ASTM D422) -Verification of the thickness of the material placed under the liner(e.g., sand layer) -Measurement of the thickness of the uncompacted or loose lift at several locations in a layer of fill, using marked staff or shovel blade, with survey levels made every few lifts for verification
Compaction	Liner failure due to differntial subsidence	-Continuous field testing of compaction moisture content and density, using nuclear guage, thin-walled tube or driven cylinder to obtain undisturbed samples of cohesive soils; sand cone or rubber baloon method (ASTM D1556 and D2167, respectively) to obtainag samples of gravelly soils
Slope	Liner sliding from side slope;Inadequte gas venting	-Use of standard surveying techniques to verify side slopes and the amount and direction of bottom slope
Herbicide	Growth of vegetation through liner	-Inspection of the sterilization procedures to ensure conformity to the procedures recommended by the herbicide manufacturer -Sampling and chemical analysis to verify use of correct herbicide and application rate
Liner handling and storage	Damage due to wind, sunlight, hail and vandalism; crimps and weak spots in liner	-Visual inspection of the storage facility and conditions and of handling practices, defects in manufacturing/fabrication, damage during transportation, etc.
Materials and equipment	Use of defective or wrong material	-Inspection and/or verification of the receipt of correct material (e.g.,by comparing the suppliers material identification marks with the purchase order or catalog description), good working conditions of equipment, and correct number of pannels -Test seams to verify above

can be affected by temperature and humidity variations.

The air lance method of testing field seams is considered by some to have fewer disadvantages than the other two tests. The U.S. Bureau of Reclamation considers it an invaluable method that should be specified for all jobs involving FMLs similar to the CPE installed at the Bureau's Mt. Elbert project. However, this method only determines whether or not there is a leak across the interface and does not indicate seam strength.

The U.S. Bureau of Reclamation studied a thermal infrared scanning method of non-destructive field seam testing during the Mt. Elbert project. The theory of the test was that the IR scanner would detect air voids caused by imperfect seam bonding

TABLE 22. TESTING AND INSPECTION FOR LINER PLACEMENT, CONNECTING TO APPURTENANCES, ANCHORING AND BACKFILL PLACEMENT

Element	Testing and Inspection
Liner Placement	-Laboratory chemical fingerprinting and compatibility tests to verify liner being used is the same as selected in chemical compatibility tests
	-Inspection to verify correct placement of panels and patching and for blisters, scrim defects, delamination, tears, etc.
Anchoring	-Inspection for evidence of wind damage during installation due to inadequate anchoring
	-Inspection of anchor trench construction to verify conformance to design
Connecting to appurtenances	-Inspection to verify use of compatible materials (e.g., for pipes) and proper liner thickness (e.g., doubling) or use of geotextile cushions per specifications
Protective cover	-Inspection to verify thickness of cover material (including rip-rap for surface impoundments) and for evidence of poor equipment operation during soil placement
	-Tests for grain-size requirements and inspection for freedom from fractured stones, debris, cobbles, roots, etc.

by sensing and displaying temperature differences; the air pockets are cooler than the surrounding surface and should show up darker on the display screen. However, it was difficult to distinguish between air pockets in the seams and those caused by the uneven subsurface. In addition, the small size of the target air pockets tended to approach the resolution capability of the instrument. Thus, the test method was considered to be incapable of identifying imperfections in the field seams.

Destructive seam testing involves cutting out a sample of an existing seam for the purpose of verifying seam conditions through laboratory testing. Commonly performed lab tests for seams include those for peel adhesion (ASTM D413, Method Type 1, and D1876) and shear strength (ASTM D816, Method B, modified, and D882, Method A, modified). Test samples may be cut either from the liner itself or from specially-prepared sample seams constructed under the same conditions as the actual liner seams. These samples are usually prepared several times per day.

Peel strength tests measure the relative bonding strength between the two FML sheets in a peel mode of failure. Although this failure mode may not occur in practice, the test can be used to indicate the strength of the bond. Shear strength tests measure the strength of the bond between the FML sheets at the seam under a rapid shear loading situation such as would occur when the FML is stressed in tension during installation.

Some contend that seams are stronger in shear than in peel and that as a result the peel test is the only one of the two that is relevant. The U. S. Bureau of Reclamation prefers the peel test over the shear test because it shows how homogeneous the material is an where and when interface failure occurs. It provided them with much important information during the Mt. Elbert project. The peel test of seam strength is also more sensitive to the effects of aging and exposure than is the shear test. The results of the shear test can be improved simply by increasing the width of the seam.

When test samples are cut out of the FML, the hole should be repaired immediately with a round or oval patch made of the same type of FML material. New seams in the repaired area should be tested with the same non-destructive test methods that were used previously. Some inspectors believe that where cut-out samples are tested, the benefits gained from testing outweigh the drawbacks of having to patch an equal number of cuts in the liner.

The U.S. Bureau of Reclamation used both cut-out samples and prepared samples for destructive testing at Mt. Elbert. They found that the peel failure rate was significantly higher in the field cut-out samples than in the field fabricated samples and attributed this to the better workmanship exercised in preparing samples that were known to the workers to be intended for test purposes. On the other hand, some contractors contend that cutting out samples for destructive testing should be minimized because the integrity of the patched seams is uncertain. Some also recognize, however, that when the seaming crew knows where samples are to be taken they are likely to do an especially careful job in that location, and that such samples are not representative of overall field seam quality.

Although contractors report no difficulty with patching holes from cut-out samples, some do suggest an alternative. This is to surprise the seaming crew by periodically requiring them to construct a seam on scrap material using the exact technique that was just being used on the liner. For example, if the weather is cool and the crew was not using a heat gun, no heat gun is permitted on the test strip. This method is said to give a fairly representative indication of how well the seams are being constructed.

Seams in special locations (e.g., around pipes and appurtenances) should be nondestructively tested if the seam is accessible to testing equipment. If the seam cannot be tested in-place, but is accessible to testing equipment prior to final installation, the seam should be nondestructively tested at that time. If the seam cannot be tested either in-place or prior to final installation, it should be inspected for uniformity and completeness.

If seams not meeting specifications are detected during inspection and testing, further testing should be done in both directions to the point where the seam again meets specification requirements. Then a cap strip should be placed over the suspect seam between the points where the seam meets the specification requirements. The cap strip should then be seamed using standard seaming methods (applied with extra care). Upon completion of all repair work, the full length of all seams should be reinspected to ensure that all defective areas were repaired or completed.

B.2.3 Leak Detection and Repair for In-Service Liner Systems

Leaks in the liner can be detected through the use of subdrain leak detection systems, ground water monitoring or methods such as acoustic emission monitoring, time-domain reflectrometry and electrical-resistivity measurement, which are currently under development. Pertinent features of these leak detection systems (LDS), including their advantages and limitations, are listed in Table 23. Provided that the effectiveness of a subdrain LDS can be demonstrated before the system is placed in service, at this time the subdrain system appears to be the preferred method over ground water monitoring or the survey methods which use the developmental technologies.

TABLE 23. METHODS FOR DETECTING LINER LEAKS

Method	Description	Advantages	Disadvantages
Subdrain Leak Detection System	A lysimeter type system generally consisting of perforated pipes embedded in sand and gravel drainage material. In double-lined facilities, LDS would be located between the liners (see Figure 21). In a single-lined facility, the perforated pipes would be placed in lined trenches (see Figure 22) which would be located below the liner along the length of the facility. The LDS drainage pipes are sloped to convey the leachate to catch basins or observation wells.	-Direct evidence for occurrence of leaks.	-In a double-lined facility, a break in the integrity of the secondary (lower) liner may reduce system reliability. -Might be difficult to remove rainwater which may seep between the liners during construction; chemical analysis may be required to distinguish such seepage from actual leakage through the liner. -In a single-lined facility, LDS may not detect leak unless the LDS covers a significant area under the liner. -May fail to detect minor leaks.
Ground water Monitoring	Observation of changes in water quality through sampling and analysis of water samples from strategically located monitoring wells.	-Direct assessment of impact on water quality. -Public relations appeal.	-Design of suitable monitoring system requires good knowledge of groundwater conditions and flow regime. -Monitoring systems and programs should be designed on a case-by-case basis. -Unless suitable target species species can be monitored, it may be difficult to detect minor changes in water quality due to leakage. -Installation of observation wells and subsequent water quality monitoring can be very expensive.

(Continued)

TABLE 23. (Continued)

Method	Description	Advantages	Disadvantages
Electrical Resistivity Measurement (66-68)	Since geomembrane liners exhibit high electrical resistance, conductive fluid flow through the leak establishes an electrical shunt through the liner. This low resistance shunt forms an electrically detectable region which permits detecting and locating leaks when a current source is used to inject current across the boundary of the liner. Tests at 1.5 million gal. impoundment have shown that the system can detect a 1-in. hole in the liner and can pinpoint its location within 1 ft. (67)	-Nondestructive method of leak detection. -As few as two workers are needed to perform a test, record measurements and analyze results on a computer (67).	-Method still experimental and under development. -Applicability to landfills and and full scale waste impoundments remains to be demonstrated.
Accoustic Emission Monitoring (69, 70)	Accoustic sounds are emitted when water flows in a turbulent regime through soils. Good accoustic coupling of the sensor near the liner material may permit leak detection and location.	-Nondestructive method of leak detection.	-Method still experimental and requires further development.
Time-Domain Reflectometry (69, 70)	A high frequency electromagnetic technique which can measure the electrical properties of materials in and around conductors of a transmission line. The electrical properties of a leachate-saturated soil will usually be different from those of the host soil and thus the technique will be able to detect the leachate.	-Nondestructive method of leak detection.	-Method still experimental and requires further development.

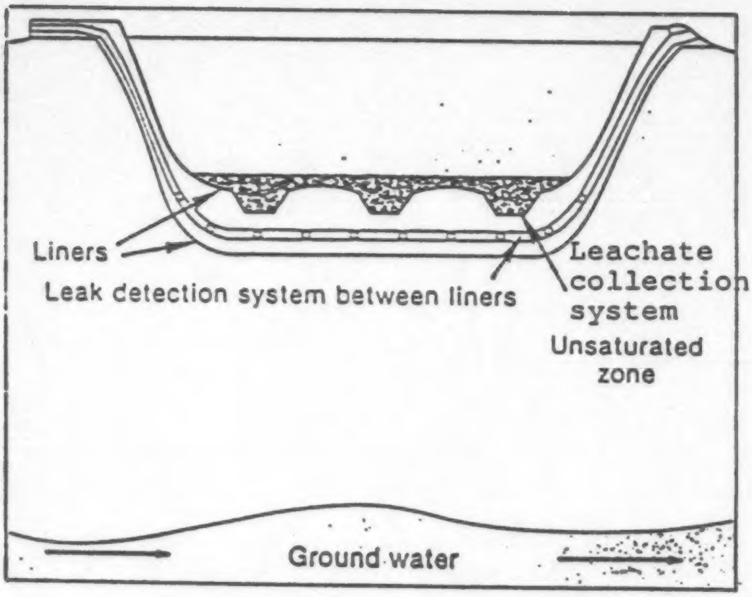
Liners
Leak detection system between liners
Leachate collection system
Unsaturated zone
Ground water

Figure 21 . Schematics of a double-lined landfill incorporating leak detection system (73)

The liner repair techniques can be broadly grouped into three categories: Patching, mechanical plugging and sealing with soil grouts. A state-of-the-art review of liner repair techniques which are being utilized in all types of emplaced liner systems has been carried out recently as part of a broader EPA-sponsored liner repairability program (69). According to this review, some repair techniques are currently being applied in the field to effect localized repairs to liner systems. These vary widely, depending upon the type of liner being repaired, the extent of problem and the expertise involved in design and implementation of the repairs. The success of these repairs is also widely variable. However, in all cases the repair of in-service liner systems is highly complex, and dependent upon a number of factors which are very site- and situation-specific. These factors include swelling of membranes due to exposure to waste or leachate, the use of dissimilar liner materials, accessibility of liner and the cost for waste removal to gain access to liner. Compartmentalization of operation and designs which provide for separate leak detection systems for individual compartments or subcells, can conceivably allow for the identification of a leaking subcell so that the repair can be limited to a smaller area rather than a very large cell or entire landfill (T.D. No. 2). This, however, would not be very practical for large landfills where cells and subcells would also be very large. Thus,

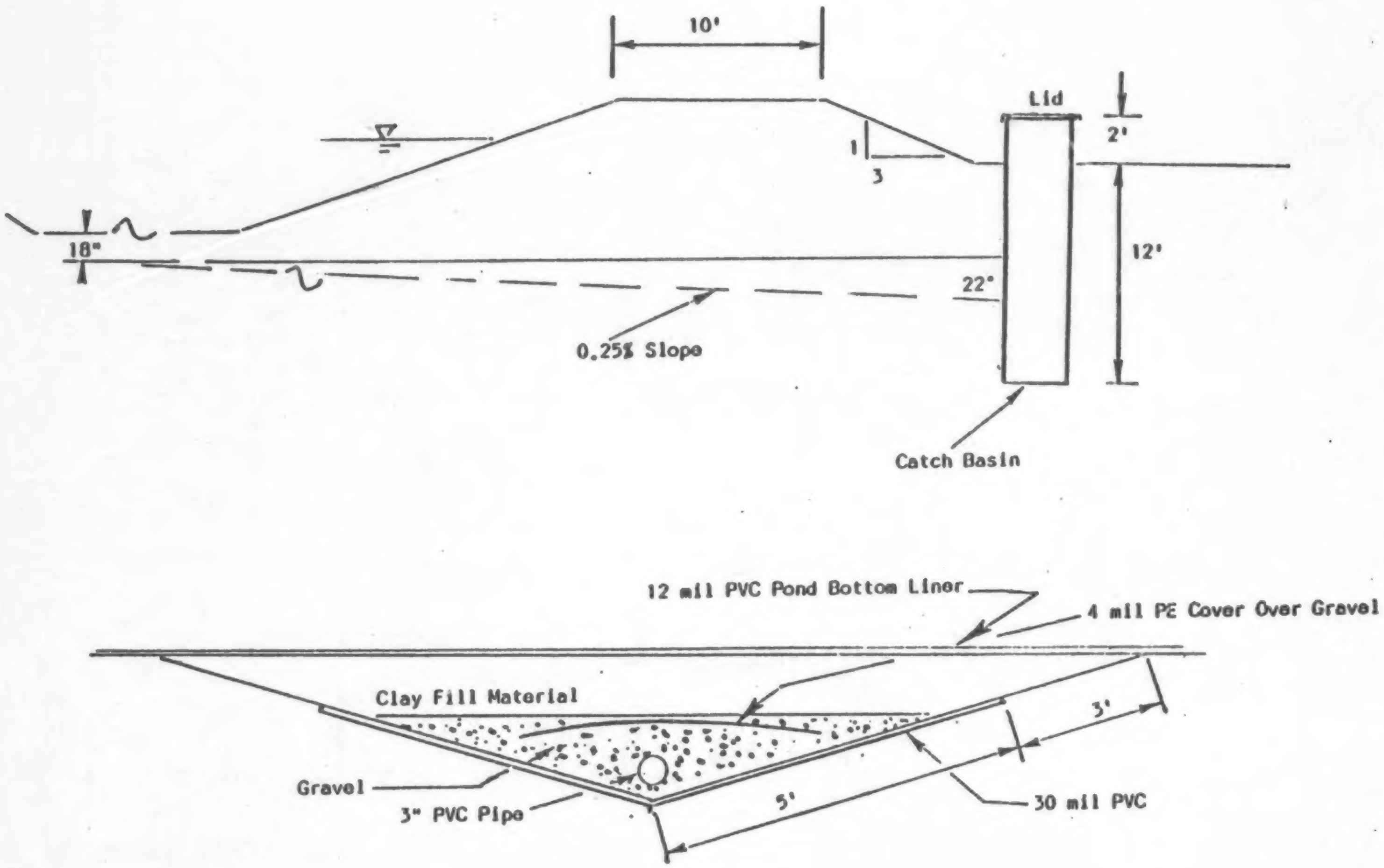
10'
Lid
2'
1
3
12'
18"
22"
0.25% Slope
Catch Basin
12 mil PVC Pond Bottom Liner
4 mil PE Cover Over Gravel
Clay Fill Material
Gravel
3" PVC Pipe
3'
5'
30 mil PVC

Figure 22. Subdrain leak detection system at a surface impoundment facility in the Southwest (2)

given the complexity of the problem, each repair solution would probably be a problem unto itself, requiring site-specific analysis and design.

Although in-service liner repair efforts have been undertaken at full-scale facilities, there has been little feedback on the success (or failure) of these attempts and there has not been any systematic analysis of the circumstances involved, repair procedures used, costs incurred and results obtained. Under EPA sponsorship, a laboratory study is currently underway (69) to evaluate the promising liner repair techniques and to develop the data base for (a) technical and economic assessment of existing repair technology, (b) identification of gaps in existing techniques, and (c) definition of future research direction. Broad goals of the laboratory evaluation are as follows (69):

- An assessment of field seaming procedures for in-place repairs, including those recommended by manufacturers, as well as "tricks-of-the-trade" applied by practitioners in the field
- The feasibility of drying out and repairing a dried out piece of previously exposed liner
- The reliability of a variety of adhesive bonds after exposure to several leachates under both shear and peel testing
- Preliminary injection parameters for various repair compounds: epoxy resins, silicones, chemical and particulate grouts
- Durability over time of the same compounds (by destruction testing)
- The feasibility of conducting repairs under several different conditions, as in leachate impregnated soils or in the presence of running or stagnant water

Although the above laboratory program is seen as exploratory in nature, the importance of conducting the first stages of laboratory evaluations of liner repair systems under controlled conditions with the total procedure exposed to view cannot be overestimated. Once these issues are well understood, work will be extended to include attempts at field repairs in difficult-to-access environments, underneath or at the bottom of in-service impoundments.

In another ongoing EPA-sponsored study (71), several concepts for retrofitting liquid surface impoundment facilities with synthetic membrane are being evaluated. Retrofitting of membrane liner systems offers a potential for reducing or stopping seepage at a leaking site. The procedure may be used as a permanent step to upgrade a leaking or untrustworthy facility, or as a temporary measure while a new replacement facility is being constructed. Also under investigation under EPA sponsorship is the determination of the geotechnical feasibility of utilizing selected grouts and state-of-the-art techniques in solving the problems associated with the in-situ bottom sealing of existing hazardous waste sites (72).

B.2.4 Cover Settlement: Causes, Prevention and Repair

The function of the cover or cap is to prevent infiltration of precipitation into landfill cells. The cover is usually constructed with low permeability synthetic and/or clay material and with graded slopes to enhance the diversion of water. Cover subsidence or settlement has been identified as one of the most critical factors resulting in poor landfill performance (73, 74). Subsidences can bring about cracking or collapse of cap and localized depressions, allowing ponding and increased infiltration. Causes of subsidence are primarily shifting, settling or release of landfill content over time. Although a certain degree of uniform subsidence can be handled through proper cover design, differential settlement is more difficult to predict and mitigate through design. The following excerpt from Ref. 73 illustrates the problem:

> Comparatively uniform subsidence might be expected to occur for landfills containing one form of waste (i.e., a monofill). Many landfills, however, contain a variety of wastes, both containerized and in bulk. Bulk liquids and sludges provide little internal structural support. Vaporization may also be a problem. Containers do provide short-term support, but they deteriorate, often within a few years. The rate of container deterioration is difficult to predict; it depends on site- and waste-specific factors. It may not be possible to compact a mixed waste landfill sufficiently, e.g., compaction comparable to preparation of a building foundation. Further, the internal structure of the landfill cells is constructed of compacted support walls, which retain their original height while the wastes within settle. Cracking around the perimeter of the cover has resulted. Finally, the extraction of collected leachate produces void spaces and exacerbates settling.

Some of the design and operating procedures which are aimed at management of leachate and gas migration/emissions can reduce or enhance the potential for cover failure due to subsidence. Thus, leachate and gas extraction, which promotes waste consolidation, would also enhance potential for waste settlement.

On the other hand, leachate and gas control, through source control measures such as limiting disposal of bulk liquids, solvents or solidifying waste prior to placement, which would enhance the structural stability of the landfill, would also reduce settlement potential. Because of these conflicting effects and objectives, the subsidence problem and its mitigation should be addressed in the context of an overall waste management plan and objective and on a site-by-site basis. In general, the applicable preventive and corrective measures for cover subsidence problems include the following:

- Proper cover design (see Refs. 1, 5 and 7 for analysis and procedures)
- Source control
- Progressive design and multiple cell design for segregated waste disposal (see Table 5 for description)
- Placing drummed waste on its side, a position providing less structural support, in order to hasten the collapse and settling of the buried drums (73)
- Adequate waste compaction during placement and prior to installing the final cover to enhance structural stability
- Surveillance and maintenance of the cover

The ease (or difficulty) and the cost of repairing a failed cover depends on the nature and extent of the cover failure and the degree of complexity and sophistication of the cover design. The repair may require carefully peeling back each protective layer until each is found to be sound, partial reconstruction of gas venting and cover drainage system, recompaction of soil layers and revegetation of the top soil (73).

B.3 CONCLUSIONS AND R&D RECOMMENDATIONS OF THE "SURFACE IMPOUNDMENT" STUDY (2)

B.3.1 Lessons from the Case Studies

- Adequate site investigation, good project planning during the design and construction phase, and rigorous execution of a comprehensive QA/QC are essential to developing successful facilities. Problems resulting from inadequate site investigation and poor design and construction practices cannot be fully and permanently corrected through piecemeal remedies applied as the problems surface.
- Construction supervision and inspection by competent and conscientious inspectors to ensure adherence to recommended

specifications, and rigorous documentation and recordkeeping are cornerstones of an effective QA/QC program. The program should cover all steps (i.e., planning, design, construction, etc.) leading to the development of a completed facility and should encompass all system elements, support facilities, operations and corrective measures (i.e., monitoring wells, leak detection subdrains, dredging, repairs, etc.)

- QA/AC programs for facilities lined with FML should emphasize liner-waste compatibility as a criterion for liner selection, proper installation procedures (particularly in the seaming step), and the use of protective cover (especially when the liner would be exposed to severe stresses of the elements).

- Unless properly designed, ground water monitoring programs would not be reliable substitutes for subdrain leak detection systems. These systems would be more reliable in providing advance warning of a site failure, thus allowing appropriate measures to be implemented in a timely fashion.

- The successful performance of surface impoundments at two of the facilities studied is attributable to: (a) use of a very impermeable clay as liner material; (b) extensive waste-liner permeability studies; (c) use of competent design, construction, and inspection contractors; (d) close scrutiny of all phases of design, construction, and QA inspection by the owner/operator; (e) excellent QA/QC and record-keeping during all phases of the project; and (f) good communication between all parties involved in establishing the sites.

- Case studies documenting the performance of hazardous waste facilities (successes and failures) can provide the feedback needed for evaluating the performance of various designs and construction techniques and can yield valuable lessons for improving design, construction, monitoring and operating procedures.

- The nine case study facilities reviewed here were selected from a much larger number of sites that were screened for suitability to the study objective. Many facilities were rejected because of one or more of the following reasons: (a) not representing an engineered site, (b) presence of other actual or potential sources of pollution at the site, (c) little or no data available on the hydrogeological settings and site construction, and (d) no or insufficient monitoring data to enable performance evaluation. Based on the sample of SIs examined, these rejected facilities more accurately represent the existing SI practices than the nine case studies that were selected for design versus performance evaluation.

B.3.2 Professional Opinions and Experience of Experts

- Siting in suitable geological formations is the best protection and the first line of defense against ground water contamination, regardless of whether the facility will be lined with FML, clay, or other liner types.

- In the "intragradient" design, in which the facility is intentionally located in the saturated zone, the high ground water table provides a positive pressure that can prevent release and outward migration of leachate or waste in the event of failure.

- Geotechnical support should be a continuous effort covering not only site investigation and facility design but also the construction activities. The support is especially important in preparing construction specifications and during pond and borrow pit excavation, when major changes in soil properties must be detected and appropriate modifications made to the original design and construction specifications.

- Even with the soundest design and support studies, the adequacy of a completed facility cannot be guaranteed without assurance that the construction has been carried out according to specifications. This underlines the importance of an effective QA/QC program, the key elements of which should include thorough construction inspection, use of competent and conscientious inspectors, and detailed documentation and record-keeping.

- The most critical factor in clay liner construction is compaction under proper moisture conditions. Compaction should be aimed at eliminating all air spaces and not necessarily at achieving certain arbitrary Proctor density levels. Compaction wet of optimum is generally sufficient to ensure elimination of air spaces and development of a very impermeable liner.

- Desiccation cracking of clay is a highly site- and situation-specific problem that depends not only on the type of clay and its silt content but also on the moisture level and construction technique. Since liners are constructed in lifts and there is little chance for alignment of cracks in adjacent lifts, a limited number of shallow cracks that may go unnoticed during lift inspection should not present a major leakage problem.

- Selection of suitable liner material, use of proper installation procedures, rigorous QA/QC, and providing and maintaining protective cover for the liner are critical factors in ensuring a successful FML installation.

- Even though waste-liner compatibility tests provide valuable data for selecting a suitable FML, a problem often encountered is that the characteristics of the waste that will come in contact with the liner are not known at the time of design and that the characteristics may change during site operation. Thus, the compatibility issue should be re-examined any time the character of the waste changes.

- Practical measures for mitigating the liner-waste incompatibility problems relate to good site design and operating practices and include waste segregation, pretreatment and banning disposal of certain wastes.

- FML field installation problems can be minimized by the use of experienced workers who will carry out the actual installation. Providing good field supervision and technical assistance to the installer, and minimizing field seaming by use of larger liner sections (whereby much of the seaming has been done in the plant) will also minimize problems.

- Providing and maintaining protective cover for a liner is extremely important in preventing damage as a result of the elements and minimizing problems because of vandalism, pinholes, animals, and chemical incompatibility.

- Use of FML in conjunction with clay in a double liner system would take advantage of the desirable properties of both liner types and compensate for the possible shortcomings of the individual systems. Where such combination systems have been used, the design calculations, however, rely solely on clay as the protector, assuming that FML would not be available as a backup system.

- Despite considerable improvements that have occurred in the recent past in leachate collection systems design and construction, the apparent sporadic plugging of the underdrain systems remains a problem area. At the present time, there is no practical corrective measure for restoring the hydraulic capacity when a sand and gravel drainage system is plugged.

- Subdrain leak detectors, which permit direct observation, have merits over monitoring wells (or other indirect methods) by allowing more rapid detection of failure, permitting monitoring over a relatively large area under the liner and yielding more reliable results. Unless ground water monitoring is tailored to the specific hydrogeological and other features of a site, it may prove inadequate in providing a true picture of the background conditions and changes in water quality.

- The proposed California regulations, which require double lining with clay and FML in addition to siting in Class I areas is considered by some to be unnecessarily overstringent. This apparently excessive stringency is based on the state's experience that (a) even some well designed facilities that have used the state-of-the-art technologies have failed, (b) geological deposits are often discontinuous and the potential for lateral or vertical migration of waste cannot be fully eliminated, and (c) when damage occurs, the cost of cleanup can be very high.

- The requirement for the use of FML in state regulations is primarily in response to the requirement in the current interim final RCRA regulations.

- A considerable amount of accumulated experience in the waste disposal field needs to be collected, analyzed and disseminated as a technical manual that discusses in some detail how all of the elements of facility site selection, design, construction, operation, monitoring, maintenance and repair fit together.

B.3.3 R&D Recommendations

- Extension of the present study to include additional case studies and experiences of technical experts, with dissemination of the extended study results to practicing engineers, owners/operators of hazardous waste management facilities, regulatory agencies and active researchers.

- Evaluation and documentation of the effectiveness of various FMLs, seaming methods, QA/QC procedures for installation, and FML compatibility with various wastes/leachates under field conditions.

- Development and standardization of practical and economic waste-liner compatibility tests for use in liner selection and as a means for accepting or rejecting waste loads by facility operators. The effort should include development of practical tools for predicting the characteristics of leachates from landfilling of various waste types.

- Investigation and documentation of the "intragradient" and the "hydraulic barrier" design concepts for landfills and surface impoundments.

- Identification of proper design, construction and operating practices that would minimize the potential for clogging of the leachate collection systems and development of corrective measures for clogged systems.

- Development of laboratory procedures and practical field methods for obtaining clay permeability data for use in design.

- Development of new concepts and protocols for early detection of site failures and corrective measures, and evaluation of currently proposed systems (e.g., resistivity and acoustical measurement methods) under actual conditions.

- Development of technical basis and criteria for proper design of ground water monitoring systems with respect to number, location, and depth of monitoring wells.

- Development of reliable, maintenance free, and retrofittable techniques for monitoring the unsaturated (vadose) zone. This should be supplemented with an effort to compile and evaluate data on mobility, attenuation, and persistence of waste constituents in both the vadose and saturated zones.

- Development of reliable and cost-effective methods for pinpointing the location of liner leaks, repairing leaks (especially in landfills), and mending liners that have been in contact with waste and/or the elements for a number of years.

B.4 SUMMARY AND CONCLUSIONS OF THE "LINER STUDY" (1)

B.4.1 Objectives, Data Sources, and Scope

The Environmental Protection Agency's Office of Solid Waste (OSW) is currently engaged in a review of the Part 264 land disposal regulations (promulgated in July 1982 as Interim Final Regulations) to determine if there are areas where regulatory reform would be appropriate. One of the areas which is being reviewed relates to the requirement that liners and caps for new land disposal facilities prevent migration of waste during the active life of the facility and minimize migration during the post-closure care period. In this connection, and under a contract with OSW, TRW has collected and reviewed data on liner installation practices and has developed a data base on installation problems, applicable mitigation measures, and related R&D needs. The data base presented herein consists of information from the open literature supplemented by up-to-date data collected through some 40 interviews with technical experts in industry, state regulatory agencies, trade/professional associations, research organizations, and waste management companies. The interviews with the experts had a much broader objective than determining installation problems alone. They also covered other problem areas such as liner design, manufacture, and fabrication, which can be very critical in developing an adequate liner, either alone or in combination with installation factors. The reports on the interviews have been assembled separately in a Volume I entitled "Data Base Development: Perspectives of Industry Experts, State Regulators, and Owners and Operators".

This Volume II report, which focuses only on liner installation problems, contains the data base and the analysis for answering two related questions of critical importance to EPA in its review of the liner regulatory requirements. These questions are as follows:

- Can current technology and know-how allow construction and installation of bottom liners and cap systems so that they meet designed performance capabilities?
- Are the proper technology and know-how actually used in practice to produce installations that meet designed performance capabilities?

As used in this report, the term "installation" refers to all field activities related to preparation of the site to receive the liner and the actual installation effort (i.e., liner placement, compaction, seaming, backfill placement, etc.). The liners which have been addressed are clay, flexible membrane (FMLs), admixed, and sprayed-on liners. Since a number of issues and practices are common to all liner types, in the following discussion these points of commonality are highlighted first, followed by a review of the issues specific to the individual liner types. Research and development needs for addressing areas of uncertainties are identified and a number of key overall conclusions are presented.

B.4.2 Issues Common to Clay, FML, and Other Liner and Cap Materials

Under existing regulations, land disposal facilities must be constructed to include a bottom liner, waste piles and landfills must include a leachate collection system, and closed facilities must be capped. The operations associated with installing these systems may be categorized broadly as follows:

- Preparation of the foundation upon which the liner or cap will be supported.
- Placement of the liner or cap.
- Construction of a leachate collection system as well as leak detection system for facilities with double bottom liners.
- Placement of backfill as protection for the liner or cap.

Each step, with exception of actual placement of the liner or cap, is generally common to installation operations at all land disposal facilities no matter what type of material actually constitutes the liner or cap. These common operations are summarized briefly within this section while the steps associated with actual placement of the liner or cap, which vary with the type of material, are addressed in subsequent sections.

Preparation of Foundation--

The bottom liner should not be required anywhere in the facility to lend structural support to the contained waste. The liner largely derives its strength from the foundation such that the integrity of the liner can be only as good as that of the underlying foundation. Problems associated with constructing the foundation generally are as follows:

- Compaction to less than the required density (resulting possibly in later differential settlement which can induce stresses in the overlying liner).
- Permitting the foundation to develop a moisture condition that is incompatible with subsequent liner placement steps.
- Inadequate surface finishing to reduce the potential for liner puncture (this is generally a concern for FML only).
- Inadequate sterilization of foundation soils to suppress the growth of vegetation which can potentially penetrate the liner.

There is little data (mostly from limited case studies) to substantiate the quality of already constructed foundations and, therefore, little basis on which to judge the adequacy or prevalence of typical construction practices. However, in general, each of the listed problem areas should be manageable by properly applying techniques and practices which are already used in earthwork projects. It is the role of the quality assurance program to ensure that such practices are actually utilized. Also, certain consequences of the above-listed construction problems, if allowed to occur, can be readily identified and corrected during subsequent operations in the overall facility development. For example, substantial differential settlement occurring shortly after construction or puncture of the liner by sharp objects in the subgrade can be repaired during placement of the liner or shortly thereafter.

Construction problems can also arise from factors which are primarily design issues, and the quality assurance program generally has little control over these. Some foundation designs are incompatible with construction equipment and techniques, in particular sideslopes are sometimes specified too steep.

Developing a supporting surface for caps can be a more difficult task than for the bottom liner because many wastes are not easily compacted. As for bottom liners, little data is available regarding the adequacy of the supporting surface prepared for caps.

Construction of Leachate Collection and Leak Detection Systems--

Leachate collection systems are required by the interim regulations for waste piles and landfills to maintain the hydraulic head of leachate over the liner below 30 cm. Leak detection systems are installed in between the two liners of double-lined facilities. The principal construction problems surrounding both of these systems relate to the severe stresses that the collection pipes are subjected to during installation. The pipes for leachate collection systems are laid close to the liner in an appropriate bedding and are backfilled both to protect the pipes from overlying stresses (the waste and vehicle traffic) and to provide a suitable drainage course for the leachate. The magnitude of stress transmitted to a pipe by a load applied to the overlying backfill is very sensitive to the depth of backfill. Therefore, a pipe that is adequately protected by its final, design depth of backfill may be highly susceptible to failure until that depth is actually in place. Under most circumstances, the leachate collection or leak detection piping network can probably be installed without significant damage by applying very careful techniques of backfill placement and by eliminating construction equipment traffic over the pipes until the backfill has been placed to its design depth. However, there is no data to determine how successfully leachate collection or leak detection systems are installed in practice.

Under some circumstances, it may be especially difficult to construct the piping network without some damage to it and possibly the liner. The configuration of the leachate collection pipes and the vertical clearance over the liner are determined by the allowable head of leachate over the liner and the transmissivity of the backfill. When these factors require that the collection pipes be closely spaced, it becomes difficult to provide a backfill that will both protect the pipes and permit flow of leachate to them. The backfill must also be so designed that it does not clog the collection pipes.

An additional problem associated with leak detection systems is that failure of a pipe can initiate piping of the sand or other soil material between the two liners. Localized subsidence is then likely, resulting possibly in a failure of the overlying liner.

Placement of Backfill--

Backfill includes any cover material placed over a liner (including over the leachate collection system for waste piles and landfills as discussed) or cap to protect it from mechanical, weather, or other environmental damage such as exposure to the elements, vehicular or animal traffic, hot spots within a landfill, etc. In the case of surface impoundments, the stresses on the backfill can be especially severe as wave action is usually involved. The principal problem associated with installation of backfill over bottom liners and common to all liner material types is placement of the backfill in such a manner that it remains in place on the slopes. The degree to which adequate practices are utilized is not documented.

Maintenance of a cover on the cap is considered the most expensive element of post-closure care. As is the case for development of a suitable supporting surface for the cap, adequate compaction of the backfill is sometimes not possible due to the condition of the underlying waste material. Many of the problems associated with caps can be minimized, though not eliminated, through proper design and operating practices; for example: use of appropriate slopes, use of a soil cover capable of supporting vegetation, seeding the area at the correct time of the year, etc. While little hard data exists indicating the adequacy of current construction techniques for caps, incidences of erosion, sloughing, and subsidence have been reported.

B.4.3 Clay Liner and Caps

Many of the operations and therefore problems associated with construction of a clay liner parallel those of the more general earthwork operations applied during construction of the foundation. Problems generally specific to clay liner construction are as follows:

- Where in-situ clays are involved--failing to detect and remove discontinuities from the clay such as sand or silt lenses, roots, rocks, etc.

- Where recompacted emplaced soil liners are used--inadequate protection of stockpiles from contamination.

- Failing to attain the desired permeability which generally results from the difficulty of ensuring that conditions in the field closely meet those specified in the design specifications.

- Prevention of cracking, particularly by desiccation, between the time that the liner is completed and when it is backfilled or put directly into service.

For facilities with in situ clay deposits (i.e., facilities that rely upon in situ geological formations to contain wastes), a potential problem is the presence of secondary permeabilities (cracks, sand lenses, silt lenses, etc.) that provide potential paths for transport of contaminants toward ground water. These discontinuities, particularly silt lenses, are difficult to detect. Over-excavation and recompaction (remolding) of the clay results in a much more homogeneous barrier material. However, certain natural clay deposits are not efficiently remolded due to natural compression conditions. Thus, in determining the technology to be used for producing a soil liner, information on both natural preconsolidation pressure of the soil and the presence of discontinuities should be considered.

Stockpiles of clay to be used for liner or cap material require special care to avoid contamination, significant changes in moisture content, or material loss by erosion. Mitigation measures which have been used successfully in other earthwork projects include covering the material (or seeding if it is to remain in place for a significant length of time), inspection to detect and remove contaminants, and addition of water if necessary to adjust moisture level to near optimum prior to placement.

Adequate compaction and therefore permeability requires that the clay soil conditions closely approximate the design specifications determined by laboratory testing. Potential problems with the use of laboratory permeability tests to predict hydraulic conductivity of the field liner include the following:

- Samples may not be representative because the volume of soil tested is minuscule compared with the volume of the soil liner, composite samples produce less realistic results than separate samples, or many laboratories often discard deleterious substances in the samples.

- In the field, clay clods up to one foot across are sometimes found, but in the laboratory, clay clods are broken down into smaller sizes. Permeability may be significantly affected by the size of the clods of clay that exist in the soil before it is compacted.

- The lowest permeabilities correspond to the condition when the soil is compacted at wet of optimum moisture content. It is critical that the compaction moisture content of laboratory samples match conditions in the field.

- Permeability of compacted soil is also a function of the compactive effort. If the compactive effort in the field is less than in the laboratory, the field permeability may be much higher than expected due to a shift in optimum moisture content. It should be recognized that the method of compaction in the lab will never precisely reproduce compaction in the field by heavy equipment.

- There is little chance of obtaining representative desiccation cracks which increase permeability in small, undisturbed samples.

- Use of the wrong permeate and excessive hydraulic gradients are areas of potential problems in laboratory testing.

These problems can be mitigated by the use of laboratory permeability tests for general guidance during final design in conjunction with field permeability tests for construction verification. Field tests can be conducted on individual lifts of the compacted clay, or on the completed liner. Construction should be inspected to ensure that deleterious materials are not used, that moisture content and compactive effort are correct, that large clay clods are adequately broken up, and that the liner is not allowed to dry out. To prevent desiccation before the liner is placed in service, a soil layer or synthetic material should be placed atop the liner.

With exception of operations associated with reforming in situ clays, the same problems occur for cap installation as for bottom liner installation. However, clay cap compaction can be particularly difficult as the underlying waste may be spongy.

For both clay liners and clay caps, the associated installation problems can be largely overcome by using current construction practices combined with a comprehensive quality assurance program. Little data exists to rigorously evaluate the adequacy of these practices or determine their prevalence.

B.4.4 Flexible Membrane Liner and Caps

Operations specific to installation of flexible membrane liners and caps are storage and handling of the material, liner placement, seaming, and certain aspects of backfilling.

Storage and Handling--

Proper storage and handling of liner materials at the job site is necessary to prevent their degradation due to exposure to unfavorable weather, vandalism, and repeated folding and unfolding. These potential problems can be handled by measures such as storing the liner in a secured area; scheduling to reduce time between delivery and placement of the liner; avoiding unnecessary folding and unfolding; and inspecting materials to identify and correct problems.

Liner Placement--

Problems associated with placement of the liner include:

- Placement of panels in a wrong configuration (e.g., seams on sideslopes oriented parallel rather than correctly perpendicular to the side).

- Placements that bridge a gap between two surfaces (e.g., at penetrations).

- Improper timing (for example, placement during inclement, including windy, conditions).

- Placement of the liner with little clearance between it and the leachate collection pipes. This is often unavoidable per the requirements of the leachate collection system, but any ruptured pipe could potentially puncture the liner.

The problem of improper configuration can be avoided through proper design (including identification of panels by number at manufacture and fabrication) and strict adherence to design specifications. Bridging can be avoided by ensuring complete liner contact with the supporting soil and proper compaction of the subgrade around connections (to reduce subsequent settling). anchoring during anchor trench backfilling can reduce liner damage. Although data are not available to document incidences of liner damage due to the above placement-related factors, the problem of wind damage is reportedly to be widespread.

Seaming--

Seaming is perhaps the most critical operation in the installation of FML liners and caps. The following are certain factors of good seaming practice to avoid common problems:

- Seaming procedures can vary for different liner materials and for the same material produced by different manufacturers. These differences should be carefully noted as plans for the seaming operation are drawn up.

- Experienced labor, at least at the foreman level, is necessary to address adequately any unexpected problems.

- Weather conditions should be compatible with the seaming operations; in particular, excessive moisture, wind, and extremes in temperature should be avoided.

- Solvents or adhesives, where these are used to make the bond, should be applied exactly as specified. Neither too little nor an excess lends itself to adequate seam strength.

- Likewise, pressure should be applied to the seam in accordance with specifications.

- Slack and wrinkles should be removed, except those included intentionally to allow for thermal expansion/contraction.

- Special attention should be given to making connections between the liner and structures.

- Special precautions are required when new cap material is seamed to old liner material. These include ensuring that the bottom liner and cap are compatible when seamed, removal of the surface cure from the bottom liner using solvents and scrubbers, and repairing damage that the bottom liner suffers when it is uncovered.

The technology for proper seaming is available, but there is some evidence that FMLs are not always seamed properly in practice. Seaming FMLs presents many opportunities for mistakes and unintentional as well as deliberate deviations from recommended practices. Use of reputable installers, development of clear and concise specifications, and implementation of a comprehensive quality assurance program are essential to constructing adequate seams.

Checking to ensure proper positioning of the liner panels, clean seaming areas, proper overlaps, and suitable weather conditions should be included among the quality assurance measures for seaming. In addition, test seams should be made twice daily and tested in shear and peel. All seams should be tested nondestructively over their full length. The nondestructive testing should include both visual inspection and at least one other applicable method (e.g., air lance, vacuum, or ultrasonic testing). Some experts believe that while nondestructive testing is necessary, it only provides information on the effectiveness of the seam seal and not on the seam strength. Therefore, destructive testing, whereby samples of the seams are removed and tested for strength and quality in the field or laboratory, should also be performed. Unless sampled seam areas are improperly patched, destructive testing should not affect the liner integrity, as feared by some who prefer to avoid such tests.

Placement of Backfill Over FML--

No completely acceptable method exists for placing backfill over FML; all methods are claimed to risk some damage to the underlying liner. Extra care is needed when placing backfill to avoid damage to the liner. Proper design, use of clear and concise specifications, and an effective quality assurance program to ensure adherence to specifications are essential but not necessarily sufficient to install a properly functioning backfill without liner damage. The degree to which protective measures are taken and to which damage occurs in actual facilities is not documented.

B.4.5 Other Liners and Caps

Because they are used less often, the data base for other liner and cap types is considerably smaller than that for FML and clay. Other types of liner and cap materials reviewed in this study are admixtures (bentonite-soil, mixtures, hydraulic asphalt concrete, and asphalt-soil mixtures) and sprayed-ons (catalytically blown asphalt, emulsified asphalt, asphaltic rubber, and urethane modified asphalt).

Installation problems unique to these liners relate largely to on-site mixing and conditioning to develop the desired material characteristics, and to application of the product to the subgrade to develop a uniform liner of adequate thickness. Because of the careful control which is required, a well-conceived and implemented quality assurance program which ensures compliance with product application requirements becomes essential to constructing an adequate liner. However, the adequacy of construction practices used to install specialty liners and the prevalence of their use is not documented.

B.4.6 Key Overall Conclusions and Research and Development Needs

Conclusions--

Based on the data base developed in this project, the following conclusions can be drawn:

- Little data is available to evaluate the adequacy of construction and installation techniques for bottom liners and caps, but based on the views of experts and limited case studies reported in the literature, current technology and know-how are believed sufficient to permit construction and installation of systems capable of meeting design performance. This situation underlines the importance of the quality assurance/quality control programs to ensure that the best available techniques are used during construction.

- In general, the prevalence of specific installation practices (as well as their direct impact on liner performance) is not known. Installation problems are not documented. but while little information is available in the literature, judgments by many experts interviewed indicate that adequate installations often are not made. Some information is also available in the form of reported problems that occurred some time after construction is completed. However, the connection of any such problem to a specific installation or construction operation is highly uncertain. Reflecting this situation, research and development should be directed toward systematic and carefully developed studies to document cases of liner successes and failures, and the installation and construction techniques involved. Other research and development needs identified are as follows.

Research and Development Needs--

General--

- Observation of the installation and subsequent performance of liners in actual field facilities or in "prototype" cells dedicated to systematic studies. These studies could, for example, address the behavior of liners and seams in deep and shallow ponds and under a range of exposure conditions.
- Scientific cause-and-effect investigation and documentation of the reported cases of liner failure (and successes).
- Development of improved quality control tests and better establishment of the correlation between test results and actual performance.
- Development of improved and standardized methods for analyzing results from field and laboratory tests.
- Investigation of the effectiveness of various soil sterilants and improved methods of application, and education of the users on the capability of the various sterilants.
- Determination of the most suitable configurations for leachate collection systems to minimize potential for failure during construction.
- Evaluation of alternate designs and materials for leachate collection and leak detection systems, including detection systems which can locate the source of the leak.
- Determination of maintenance practices most effective in maintaining the long-term integrity of the backfill on a cap.
- Testing and evaluation of new materials and applications (geotextiles for gas venting, for example), especially from the perspective of installation techniques.
- Investigation of use of chemicals such as lime or limestone on top of the liner to effect in situ neutralization of leachate and reduce liner-leachate incompatibility problems.

Clays--

- Development of more reliable techniques for detecting subtle discontinuities in in situ clays to ensure their removal.
- Investigation of improved techniques and equipment for uniformly distributing water to clay to develop optimal moisture content.
- Development of improved methods of determining permeability both by field tests and by laboratory tests.
- Development of methods to evaluate clay liners after placement without violating the liner's integrity.
- Assessment of the effect of subsidence on rate of infiltration through caps.
- Investigation of the possibility of using dispersants to permit compaction of the clay to a higher density.
- Development of better methods by which to evaluate contaminant transport in fine grain soils, including in fracture networks.

Flexible Membranes--

- Development of better design/construction criteria for connecting liners to concrete structures in impoundments.
- Development of better sump systems for landfills to allow more durable connections (the concept of a prefabricated unit is considered worth investigating).
- Definition of conditions where geotextiles can be cost-effectively used in conjunction with reinforced and unreinforced FML.
- Investigation of substitutes to seaming (e.g., use of a "mechanical zipper"), development of new seaming methods, and test and evaluation to generate the technical basis for more concise seaming specifications.
- Investigation of the thickness and characteristics of bedding and protective soil layers needed to protect the FML from projections in the subgrade.

Other Liner and Cap Materials

- Independent verification of data reported by suppliers on installation problems and effectiveness of specialty liners.